Environment CANADA Environnement
20229931 VOL 86- ISS 11 860400
EXC # 001
TD 171.5.C3 R43
REGIONAL PROGRAM REPORT (CANADA. EN
VIRONMENTAL PROTECTION SERVICE. PAC
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REPORT ON THE EMISSION AND CONTROL OF FUGITIVE COAL DUST FROM COAL TRAINS

Regional Program Report 86-11

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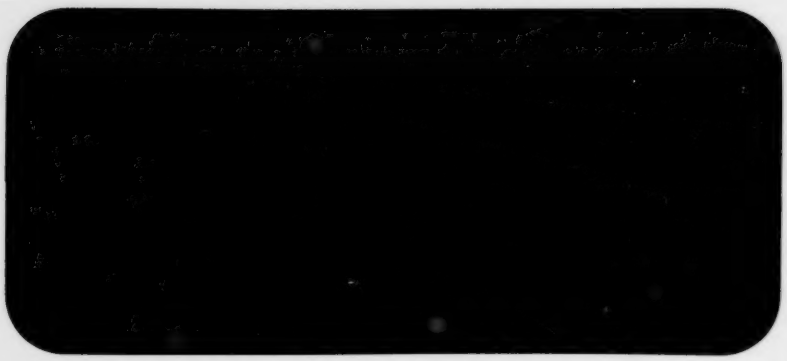

DEPARTMENT OF THE ENVIRONMENT
CONSERVATION AND PROTECTION
ENVIRONMENTAL PROTECTION SERVICE
PACIFIC REGION

REPORT ON THE EMISSION AND CONTROL OF FUGITIVE COAL DUST FROM COAL TRAINS

Regional Program Report 86-11

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APRIL 1986

REPORT ON THE EMISSION AND CONTROL OF FUGITIVE COAL DUST FROM COAL TRAINS

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The discussions in this report concern large coal operations which transport their product by rail over long distances, however, it is recognized that the movement of small quantities of coal by truck, train, conveyor or barge, over short distances, may also result in local nuisance pollution from wind-blown coal dust. Although not directly applicable, the information in this document and the listed references may be of use to small producers addressing similar coal dusting problems.

Mention of trade names or commercial products does not constitute endorsement for use.

ABSTRACT

Environmental concerns relating to fugitive coal dust emissions from rail transportation have been recognized for many years. This report summarizes various studies by government and the coal producers in western Canada on air quality impacts and various mitigation measures.

The use of chemical dust suppresssants, applied on loaded coal cars at the mine sites is recommended as the most practical control technology to minimize fugitive coal dust emissions. Cleaning of empty rail cars at the terminals is recommended as the most practical measure to minimize dust emissions from empty trains.

Mention of trade names or commercial products does not constitute endorsement for use.

RÉSUMÉ

Des inquiétudes environnementales reliées aux émissions fugitives de poussière de charbon du transport ferroviare ont été reconnues depuis plusieurs années. Ce rapport résume dfférentes études menées par le gouvernement et les producteurs de charbon dans l'ouest du Canada traitant des impacts sur la qualité de l'air ainsi que de différentes mesures de réduction.

L'emploi de supprimants chimiques de poussière, appliqués sur les wagons chargés de charbon aux mines même est recommendé comme la technologie de contrôle la plus applicable afin de minimiser les émissions fugitives de poussière de charbon. Le nettoyage des wagons vides aux terminaux est recommendé comme étant la façon la plus applicable de minimiser les émissions de poussière des trains vides.

La mention de marques déposées ou de produits commerciaux ne constitue pas un endossement pour utilisation.

ACKNOWLEDGEMENTS

In the initiation, undertaking and completion of this report on the fugitive dusting problem for coal trains, the assistance, cooperation and comments of several individuals, organizations, companies and departments are gratefully acknowledged.

Among the individuals are: J. Holmes, Environmental Protection Service Vancouver; J. Labuda, V. Shantora, A. Hazra, H. Dibbs, Environmental Protection Service Ottawa; B. Manna, K. Bhattacharyya and A. Keshvani, British Columbia, Ministry of the Environment; C. Edwards and D. Woo, Environmental Protection Service Edmonton; B. Smith, Greater Vancouver Regional District; J. Mitchell, Department of Transport, N. Agnew, The Coal Association of Canada; G. Gallagher and J. Eisler, Canadian Transport Commission.

Among the companies and organizations are; the members of the Elk Valley Coal Producers Association, Westar Mining Ltd., Fording Coal Ltd., Crows Nest Resources Ltd., Byron Creek Colleries Ltd.; the Canadian Pacific Railways; B.C. Rail Ltd.; the Canadian National Railways; Nepture Bulk Terminals Ltd; Westshore Terminals Ltd.; Thunder Bay Terminals Ltd.; Ridley Terminals Inc.; Gregg River Resources Ltd., Teck Mining Group Ltd., Luscar Ltd., Obed Coal Ltd.

The support and funding provided by the Department of Energy, Mines and Resources and the Department of Transport are gratefully acknowledged.

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SUMMARY

Environmental concerns relating to fugitive coal dust emissions from rail transportation have been recognized for many years. In the early 1970's, the increased rail traffic associated with increased coal production in western Canada was accompanied by public complaints over the environmental impact of fugitive dust emissions on communities situated along rail transportation corridors, particularly in British Columbia.

Following initial investigations in 1975, all of the major coal producers in western Canada recognized chemical sealants as the most practical method of controlling in transit dusting. Subsequently the producers commenced spraying the coal loaded in their rail cars with sealants. The installation of dust control systems in the 1970's by the coal producers in British Columbia and Alberta allowed them to make major strides toward reducing the nuisance impacts of fugitive coal dust.

Dust emissions were significantly reduced following the advent of sprays, however dusting was not eliminated. In 1979, Environment Canada, in conjunction with other federal government agencies, and the Province of British Columbia and with the cooperation of the coal industry and the CPR, reopened investigations into the fugitive coal-dust problem by establishing a monitoring station at Agassiz, B.C. where dusting and public concern were most evident. Five years of data from the Agassiz field station have indicated that continuing efforts by coal producers to reduce dust emissions resulted in a general improvement, from 1980 to 1983. However, on occasion during that period "heavily" dusting trains passed through Agassiz. The coal particulate from "heavily" dusting trains causes nuisance soiling and is unacceptable to the communities adjacent to railway tracks. In 1984 there was a substantial increase in both the number of "heavily" dusting trains and in the total number of dusting trains recorded at Agassiz. The percentage of dusting trains to total trains observed was the highest recorded since 1980.

As of August, 1985, the status with respect to fugitive dusting along the major western Canada coal-rail corridors was as follows:

- occurrences of severely dusting trains along the Fraser Valley route in British Columbia remain a public concern at this time;
- the pulp and paper companies along the northern British Columbia rail corridor have not reported any coal particle contamination of their pulp product, although two public complaints about dusting have been received from two communities along that route;

- no recent fugitive dusting incidents have been reported regarding coal shipped east by unit train from Alberta and British Columbia nor from northwest Alberta to Vancouver.

This report compiles the findings of studies and observations of the dusting incidents along the Fraser Valley route in Southern British Columbia. The report also discusses the dust mitigation measures currently in use, reviews other control options and recommends methods for improving the performance of the existing control technology.

Coal dust blown from trains is a nuisance pollutant and is not known to be a hazard to human health. With respect to government legislation, there is no federal or provincial standard which applies specifically to the short-duration nuisance pollution incidents or to coal associated with wind-blown coal dust from trains. The existing air quality objectives for particulate matter apply to total suspended particulates or total dustfall and not to coal particles. The report discusses the techniques developed for monitoring and assessing coal train dusting together with methods of assessing control system performance.

Inconsistent performance from chemical spray systems is considered the cause of the majority of the severely dusting trains seen in Agassiz, B.C. Environment Canada commissioned a series of laboratory and field studies to investigate the reasons for inconsistencies in the performance of chemical spray systems and to evaluate the areas where improvements were possible. The most extensive study involved the observation of mine-site loading and spraying operations along with the assessment of crust retention on over 2000 rail cars as they arrived at the tidewater terminals. The results of this and other studies indicated that the performance of most sealant spray systems was acceptable and that the general performance of systems causing train dusting problems could be improved and the frequency of system malfunction could be reduced by optimizing design features and operating procedures. Where coal dusting is a problem improvements to spray facilities and operating procedures in order to provide more consistent crust retention are recommended.

The percentage of crust-cover remaining or crust retention (as measured by the observed ratio of crusted area to total surface area of the load profile) on cars arriving at the unloading terminal is presently the preferred method for assessing spray system performance and dust control. The objective is to eliminate "heavily" dusting loaded and empty coal trains. Generally this objective appears to be achieved on loaded trains (depending upon weather conditions) which have a crust retention of 85%. Self-

assessment programs to ensure the 85% minimum crust retention goal is being met and maintained are recommended.

Heavily dusting "empty" coal trains have also caused nuisance soiling complaints although incidences of fugitive dusting occur much less frequently than for loaded coal trains. An external car cleaning system at an end terminal to remove loose coal which may cause dusting en route is recommended. As yet there is no practical method for removing residual or frozen coal from the inside of empty cars. Techniques for removing coal retained in cars after dumping have been tested, but have not been successful. At the present time the only practical way of limiting dust emissions from coal on the inside of empty trains is to reduce train speed when "heavy" dusting occurs. Train speed reduction is recommended in such cases.

In order to eliminate heavily dusting empty and loaded coal trains the joint cooperation of the coal mining companies, the railway companies and the coal terminal operators is necessary. Monitoring of dust emissions along routes where nuisance soiling problems are chronic is recommended.

Control options and mitigation measures other than chemical dust suppressants have also been investigated and are included in this report.

Based on the content of this report, a separate document summarizing recommended control practices for loading, unloading and spraying coal trains is being prepared by Environment Canada in conjunction with the Province of British Columbia and with the cooperation of the mining, handling and transportation sectors of the coal industry in western Canada.

GLOSSARY OF TERMS

In the text of this report the following definitions apply:

1	Automatic Car Indexing	-	The cars in the unloading loop at a terminal are automatically advanced through the rotary dumper by a hydraulic ram, not the diesel engine units.
2	Chemical Binders or Chemical Sealants	-	See Sealants.
3	Chemical Sealant Spray Dust Control System	-	The apparatus installed at a coal mine load-out which is designed to apply (spray) chemical sealants for coal dust control. These systems include: chemical mixing and storage tanks, pumps, valves, flow meters, controls, sheds, piping, headers, nozzles and load levelling equipment.
4	Clean Coal	-	The washed, product coal as shipped to market.
5	Coal Carry-Back	-	Coal retained in dumped or emptied cars. During cold weather coal often freezes and remains inside cars during the return trip to the mines. Loose coal can also remain in dumped cars during warm weather.
6	Crust or Crust Cover	-	A crust formed over a coal load as a result of applying chemical sealants to the surface.
7	Crust Retention, Crust Remaining, or Crust Cover Remaining	-	The top surface crust area remaining divided by the total coal surface-area of a loaded car, expressed as a percentage, as observed at the end terminal.
8	Dumper	-	See Rotary Dumper.
9	Dustfall Bucket	-	A device used to collect settleable particulate matter.
10	Fine Dust	-	Coal particles small enough to become wind-entrained and to carry from the surface of loaded coal cars.
11	Fines	-	A coal industry designation for the smaller coal sizes separated at a coal wash plant.
12	Frozen Coal Carry-Back	-	See Coal Carry-Back.

13	Fugitive Coal Dust	-	Coal particles emitted from loaded coal trains as a result of wind entrainment.
14	Gouging	-	The practice of removing coal from overloaded (by weight) cars in order to meet railroad capacity restrictions. A front-end loader or similar device is typically used.
15	High-Volume Sampler	-	A filtering device used to measure total suspended particulate matter.
16	Load Leveller	-	A device usually dragged across the irregular coal surface of a loaded car. It is designed to flatten the coal profile.
17	Load-Out	-	The coal car loading facility.
18	Load Profile	-	The shape of the top surface of the coal load in a rail car, viewed from either the side or the end.
19	Nuisance Pollutant	-	A substance emitted to the environment that substantially alters or impairs the quality of the environment but is not classified as a health hazard to humans.
20	ROM Coal	-	Run-of-Mine or raw coal as mined, before it has undergone any form of treatment (washing) or beneficiation.
21	Rotary Dumper	-	An unloading device that inverts coal cars to dump the load.
22	Sealants	-	Chemicals applied as solutions or emulsions to the surface of loaded coal to seal in dust particles. Also referred to as Chemical Binders, Chemical Sealants and Sealant Chemicals.
23	Sealant Chemicals	-	See Sealants.
24	Sealant Crust	-	A surface coating provided by applied chemical sealants.
25	Sealant Volume	-	The quantity of concentrated, commercial-strength chemical sealant applied to each car.
26	Sill	-	The top flat surface of the side and end walls of a coal car.
27	Solution Volume	-	The total quantity of solution (or emulsion), obtained by mixing the commercial strength sealant (sealant volume) with water, applied to each car.

28	Spray Systems	-	The equipment installed to apply chemical sealants to coal cars.
29	Trestle Dumping	-	An unloading system used with bottom dumping coal cars. Cars run onto an elevated trestle and unload through the bottom of the car.
30	Tonne	-	A metric ton.
31	Unit Train	-	A train carrying only one cargo from loading point to unloading point.
32	Wind-Blown Coal Dust	-	The same as fugitive coal dust.

REPORT ON THE EMISSION AND CONTROL OF FUGITIVE COAL DUST FROM COAL TRAINS

1 INTRODUCTION

Coal dust blown from rail cars can be a source of nuisance air pollution in residential communities situated along transportation corridors. Public complaints about nuisance coal dust from coal trains arose in the early 1970's in British Columbia where significant coal train traffic existed as a result of moving coal for export from mines in western Canada to tidewater terminals.

In addition to the nuisance problems, coal dust blown from trains represents a loss of energy and is a recognized economic loss by the coal producers. The problem of lost revenue resulting from coal losses during rail transportation has been under investigation in the U.S.A. since the 1960's (1).

In the mid-19[illegible]'s, in order to ameliorate the problems of product loss and nuisance dusting, the major western Canada coal mining companies installed spray systems to apply dust suppressant chemicals before trains departed the mine sites. The application of sealant chemicals has significantly reduced dust emissions along most routes, however, dust emissions from trains continue to be an intermittent problem in communities along the Fraser Valley transportation corridor in southern British Columbia.

Since 1979, federal and provincial government agencies in conjunction with the coal industry have been involved in renewed investigations with respect to various aspects of wind-blown coal dust emission and control. This report provides a comprehensive review of the fugitive coal dusting problem associated with coal trains and includes: a history of the problem in western Canada, an assessment of coal dust from trains as a nuisance air contaminant, a review of the work performed by or for various groups in response to the problem, a discussion of problems with existing dust control systems, a review of other control options, and recommendations for spray application systems and for improving fugitive coal dust control for trains in southern British Columbia.

2 BACKGROUND-FUGITIVE DUSTING FROM COAL TRAINS

2.1 Origins of Concern

By 1973 nuisance pollution and the nuisance soiling caused by coal dust blown from trains was causing considerable public concern in many of the small communities along the main rail lines in southern British Columbia. Concern about the deposition of coal dust in the Cranbrook area and in the communities of Kamloops, Agassiz and Surrey was expressed by the public as numerous complaints to railway companies, municipalities, Members of Parliament and government agencies (2). Most of the complaints relating to nuisance coal dust pollution prior to 1975 came from citizens and town councils in communities located from Kamloops to Vancouver. Details with respect to the areas where complaints were most frequent are presented in References 2 and 3.

2.2 Response - Initial Tests and Mitigating Measures

In 1973, in response to this public concern, Environment Canada initiated an Ad Hoc Committee on Coal Dust Nuisance from Coal Transport comprised of federal government, provincial government and industrial representatives from coal mines in southeast B.C. and Alberta. This committee determined that remedial action was required and initiated studies to evaluate the effectiveness of sprayed chemical sealants as the most practical method for dust control at that time. After completing these studies in 1975, all major western Canada coal producers exporting coal through the tidewater terminals at Vancouver, B.C. agreed to spray the coal in the trains at their respective mine sites (3).

The results of these initial studies were promising and the industry was generally optimistic about the effectiveness and potential of chemical spray systems. The mining companies agreed that a minimum of 85% of the surface of the coal load in each car (arriving at an end terminal) would be covered with sealant crust and furthermore, that a 90% coverage should be achieved by October, 1975 (2).

2.3 Renewed Investigations

The emission of coal dust from trains and the related complaints about nuisance soiling subsided after sealant sprays became operational, but dust emissions did not disappear. By 1979 increasing nuisance dust complaint from the Agassiz and Surrey areas of the Fraser Valley prompted Environment Canada to reopen the investigations with respect to the dusting problem. In 1979 Environment Canada installed, an air quality

monitoring station in the town of Agassiz, B.C. (Area E in Figure 1) near the rail lines that pass through a residential section of that town.

In addition to dust monitoring, an observation program was implemented to record visible dust episodes of both loaded and empty coal trains. Over 3900 train observations were made at the Agassiz site between January, 1979 and December, 1984. A summary of the visible dusting incidents recorded at the monitoring station is presented in Table 1 (4).

The visible dusting observations from the Agassiz monitoring station have provided a method of assessing dusting trends in that community and of reporting on the performance of the dust control measures of specific coal companies. Beginning in 1981, a reporting procedure was implemented whereby the Agassiz assessments of "heavily" dusting trains were relayed to the respective mining company representatives so the mining company concerned could check a train's loading history for possible loading or spray system malfunctions. This reporting procedure has been supported by the coal producers and has been effective in identifying problems from dusting trains and in initiating corrective action.

The Province of British Columbia and the coal mining industry have independently conducted monitoring studies at selected sites along the Fraser Valley rail corridor in order to assess the extent of the dust pollution problem and to evaluate the performance of dust control systems (5), (6), (7), (8).

In addition to the monitoring program at Agassiz, Environment Canada, in collaboration with the Province of British Columbia and with the cooperation of the coal industry, commissioned a series of studies to assess the continuing problems with respect to fugitive coal dust in southern B.C., to evaluate methods for improving the performance of the existing dust control systems, and to investigate the potential of alternative dust abatement techniques.

In 1982, three studies commissioned by Environment Canada were completed: the testing of coal dust for genotoxic activity (9), a laboratory performance evaluation of latex sprays (10), and a feasibility study of automated car covers (11). Two other investigations were completed in 1983, an extensive spray system performance evaluation of coal trains in southern B.C. (12) and a laboratory evaluation of coal train dust emission factors (13). A program designed to evaluate ambient particulate monitoring equipment as coal dust collection devices along with an assessment of analytical methods for coal dust was completed in the spring of 1984 (14).

ROUTES:
1 - S.E. B.C. TO ONT.
2 - N.W. ALTA. TO ONT.
3 - N.E. B.C. TO PRINCE RUPERT
4 - N.W. ALTA. TO VANCOUVER
5 - S.E. B.C. TO VANCOUVER
6 - SASK. TO ONT.
7 - MINTO TO DALHOUSIE, N.B.

AREAS:
A - S.E. B.C.
B - N.W. ALTA.
C - N.E. B.C.
D - PRINCE RUPERT
E - AGASSIZ, B.C.
F - VANCOUVER
G - THUNDER BAY

FIGURE 1 MAJOR COAL - RAIL TRANSPORTATION ROUTES IN CANADA

TABLE 1 OBSERVATIONS OF VISIBLE DUST EMISSIONS FROM COAL TRAINS - AGASSIZ, BRITISH COLUMBIA*

LOADED COAL TRAINS

YEAR	TOTAL OBSERVED	VISIBLE DUSTING ASSESSMENT								
		HEAVY		MEDIUM		LIGHT		DUSTING		% NOT DUSTING
		No.	%	No.	%	No.	%	No.	%	
1979	309	23	7	21	7	29	9	73	24	76
1980	323	15	5	12	4	31	10	58	18	82
1981	459	20	4	12	3	29	6	61	13	87
1982	370	15	4	9	2	25	7	49	13	87
1983	363	11	3	12	3	16	4	39	11	89
1984	465	26	6	22	5	31	7	79	17	83
Total	2289	110	5	88	4	161	7	359	16	84

EMPTY COAL TRAINS

YEAR	TOTAL OBSERVED	VISIBLE DUSTING ASSESSMENT								
		HEAVY		MEDIUM		LIGHT		DUSTING		% NOT DUSTING
		No.	%	No.	%	No.	%	No.	%	
1979	233	3	1	5	2	7	3	15	6	94
1980	278	1	< 1	4	1	11	4	16	6	94
1981	290	1	< 1	3	1	4	1	8	3	97
1982	252	2	1	2	1	4	2	8	3	97
1983	286	0	0	1	< 1	2	1	3	1	99
1984	277	8	3	5	2	3	1	16	6	94
Total	1616	15	1	20	1	31	2	66	4	96

* Ref 4.

The major coal mining companies in British Columbia have been active in a number of committees which were formed to investigate the problems of fugitive coal dusting from trains, for example The Northeast Coal Technical Committee on Coal Dust and The Elk Valley Coal Producers Coal Dust Committee. From 1979 to 1985,

through these committees and independently the coal producers have undertaken a number of studies to evaluate various aspects of fugitive coal dust control. Examples of the reports which are available to the public are as follows:

a) a review of the state-of-the-art of coal dust control strategies and methods (3);
b) an assessment of the effect of increased rail traffic to Roberts Bank Coal terminal (6);
c) evaluations of a chemical sealants (15), (16), (17);
d) a prediction of the potential impact of coal rail traffic on the Canadian Cellulose Watson Island Pulp Mill (18);
f) measurement of fugitive dust levels from coal trains near Agassiz, B.C. (7), (8);
g) a documentation of the measurement of particulates in the ambient air along the northeast rail corridor during one year of preproduction monitoring, and one year of monitoring after rail shipments commenced (19); and
h) a docmentation of the ambient air quality with respect to particulate matter adjacent to the Ridley Island Terminal in Prince Rupert during one year of preproduction monitoring, and one year of monitoring after the Port commenced operation (20).

3 PROBLEM ASSESSMENT

3.1 Coal Train Operation

In order to assess the problem of wind-blown coal dust from rail transportation it is necessary to understand and appreciate the concept of the unit coal train and the implementation of that concept as used for the transport of coal in western Canada. Many of the difficulties encountered in the design and operation of systems for the control of fugitive coal dust emissions result from certain features inherent in the design and operation of unit coal trains.

Unit trains, for reasons of economy and efficiency, haul only one type of cargo from a loading point to an unloading point or destination. Although stops do occur (prime movers are added to or removed from these trains in the mountains), no cargo is delivered or picked up en route and the shunting of cars is kept to a minimum.

A modern unit train operation is predicated upon efficiency, therefore the design of the principal components, the loading facility, the rolling stock and the unloading facility, has been integrated in order to achieve the maximum economy and speed of operation. The three components of the typical unit coal train system, the load-out facility, the coal cars, and the rotary dumper, are illustrated in Figures 2, 3 and 4 respectively (11), (21). Note that not all rail shipments of coal in Western Canada are via true "unit" trains and the adjective "unit" has been replaced in most of the text by "coal" in order to include all trains carrying predominantly coal. Regardless, this report applies equally to all large scale coal shipments via rail.

A typical unit coal train in western Canada consists of up to 112 open-top gondola cars. The combination of coal cars, motive power units plus caboose is referred to as a train set. A coal train of approximately 100 cars plus the associated engine units and caboose is approximately 1.6 km (1 mile) long.

Coal cars in train service in Canada are owned by a number of different agencies: the coal mining companies, for example the Cape Breton Development Corporation in Nova Scotia; the end users, for example Ontario Hydro on the British Columbia and Alberta to Thunder Bay routes; the private leasing companies, for example Procor; and the two major railway companies. The leasing companies lease cars to both the coal mining companies and the railway companies. The coal car fleets and train sets of the railways in western Canada in 1985 were approximately as listed in Table 2.

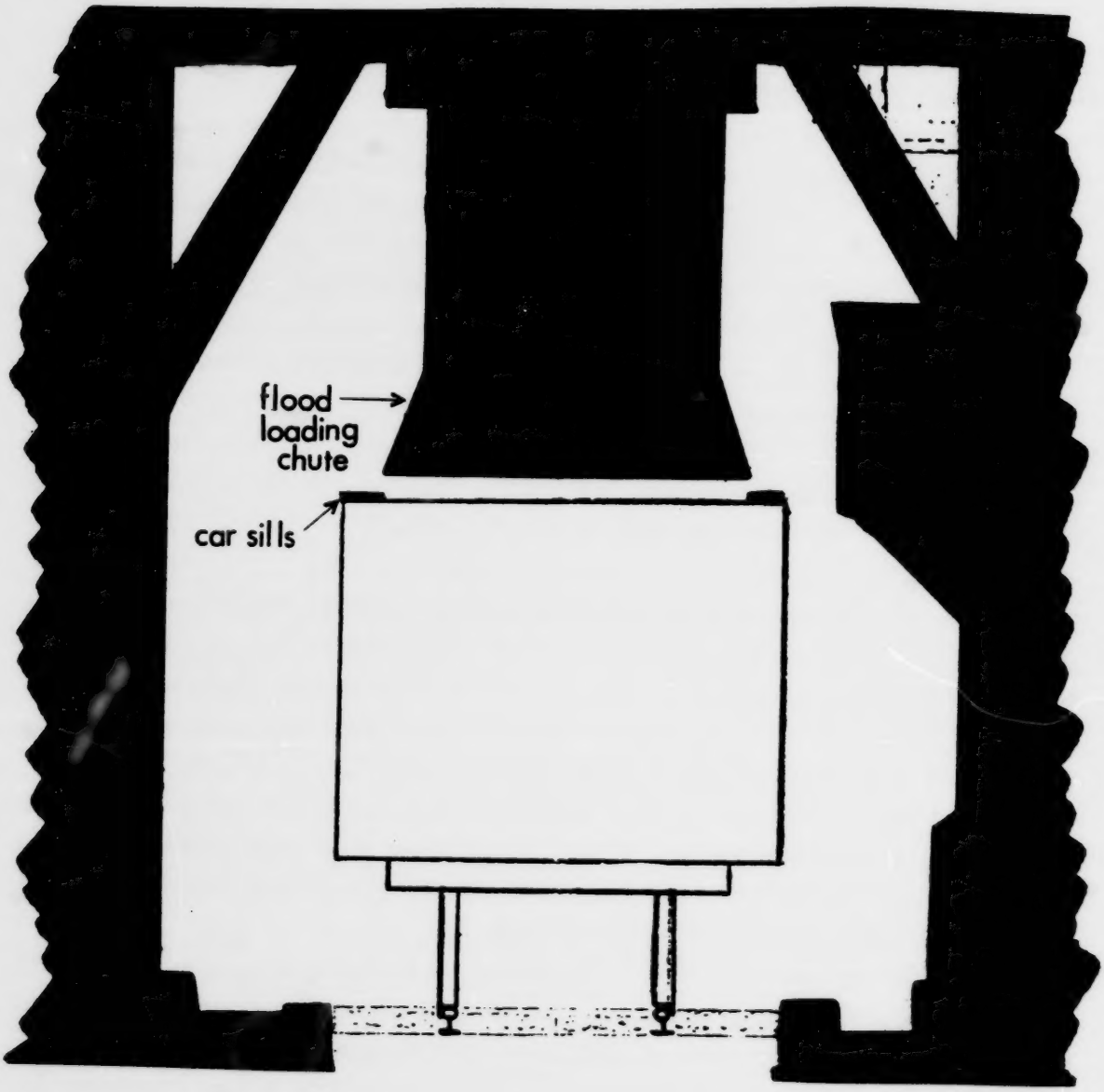


FIGURE 2 EXAMPLE COAL CAR LOAD-OUT FACILITY

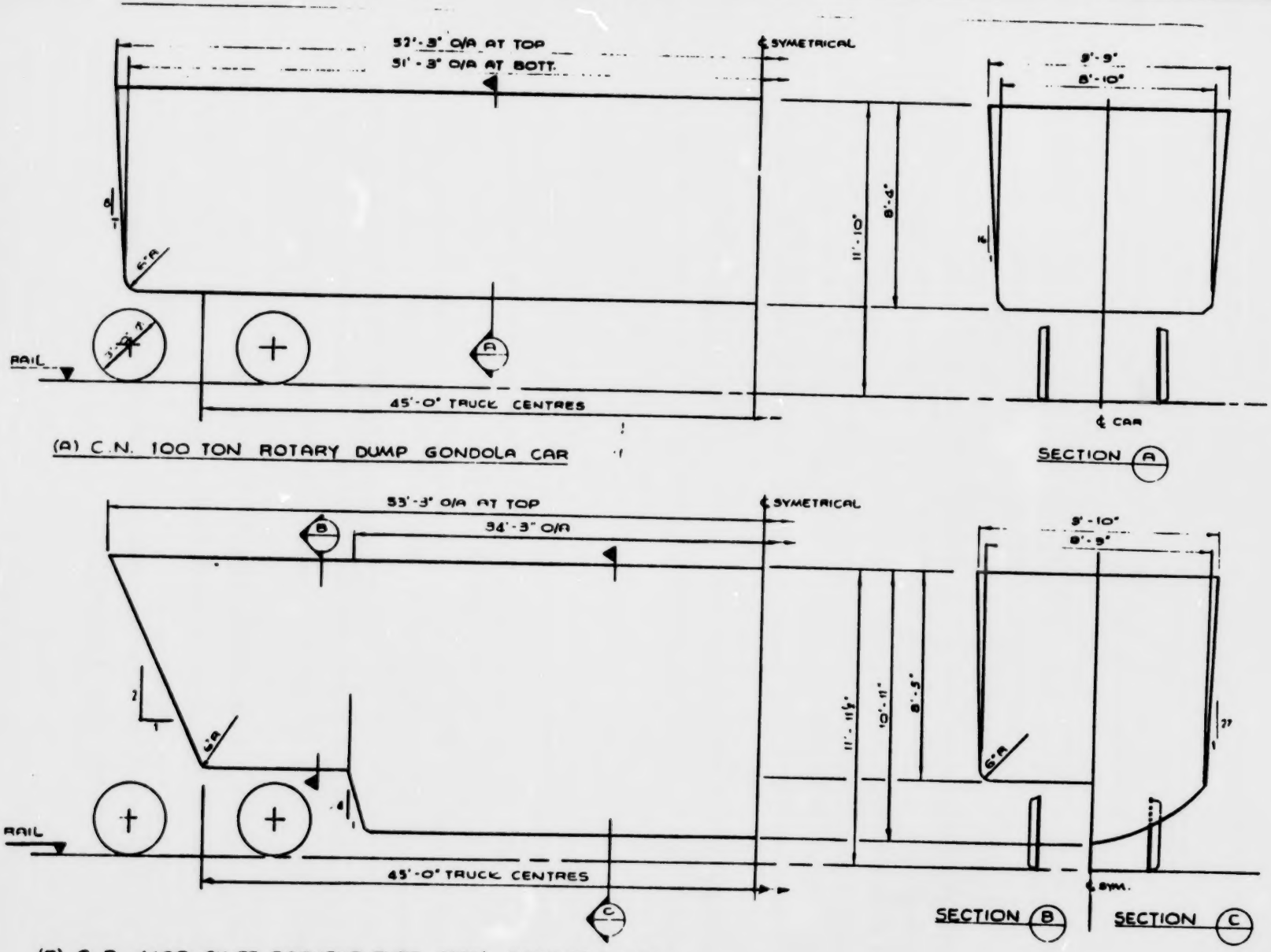
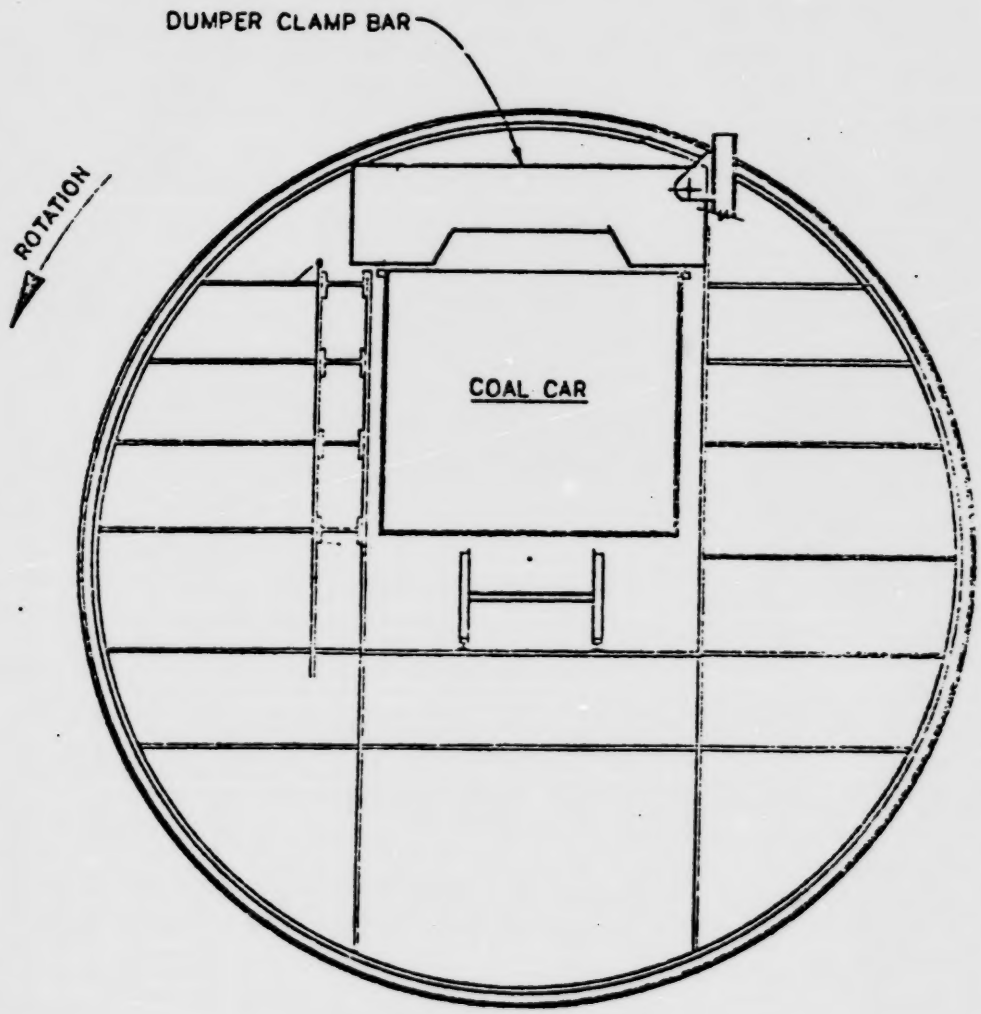


FIGURE 3 TWO RAIL CARS USED FOR COAL TRAIN SERVICE



END VIEW OF DUMPER

FIGURE 4 ROTARY COAL CAR DUMPER

TABLE 2 COAL CAR FLEETS IN WESTERN CANADA (1985)

Railway Company	CPR	CNR	BCR/ CNR	CNR Total*
Train sets	19	12	9	21
Total Cars	2250	1379	889	2268

* Includes BCR Train Sets i.e. CNR + BCR/CNR.

Railway rolling stock is manufactured in batches and although there are only two or three basic designs for gondola cars, manufacturing tolerances and minor design changes between batches have resulted in coal car fleets where individual cars within a train set can differ with respect to load capacity, tare weight and dimensions (Table 3). In general, for coal service, the Canadian railways employ 91 tonnes capacity (100 short ton) gondola cars. Detailed descriptions and illustrations of the gondola (or bathtub) coal cars are presented in References 2, 3, and 11.

In spite of size variations certain train sets comprise cars of similar size and construction so that the sill height, an important dimension with respect to coal loading, is approximately the same for all cars in the train. Coal trains operated by the CNR which service northwest Alberta, the new BCR/CNR train sets servicing the northeast B.C. Coal Development, as well as the Ontario Hydro trains loaded in southern British Columbia are in this category. However, most of the coal trains operated by the CPR which service the coal mines in southeast British Columbia and which travel the Fraser Valley route to Vancouver comprise cars of different design and manufacture within the same train set. Consequently the sill heights of the cars within these CPR train sets will often vary from car to car (10), (11), (22), Table 3. The CPR experimented with an aluminum car which had a considerably higher sill than most of the steel cars. The aluminum cars were removed from coal train service early in 1984, however, the CPR is introducing a new car which will have a lower sill height than the cars now in service, Table 3.

The largest coal exporting mines in western Canada, at peak capacity, will load two trains per day, seven days a week. Speed of operation is therefore essential in order to keep handling costs, rail charges and train turn-around times to a minimum. The mining companies will typically load a complete train set in four hours or less, and this is

TABLE 3 TYPICAL COAL CAR DIMENSIONS

Bathtub Coal Cars	Sill Height from Top of Rail	Inside Length	Outside Length
Coal Cars in CPR Trains*			
CP 349050 - 349109	13'3/8"	48'1"	58'7"
CP 349109 - 349118	13'5/8"	48'1"	58'7"
CP 349119 - 349124	12'3&1/4"	48'3/8"	58'7"
CP 349130 - 349206	13'3/8".	48'1"	58'7"
CP 349207	13'5/8"	48'1"	58'7"
CP 349250 - 349735	13'3/8"	48'1"	58'7"
CP 351300 - 351699	13'5/8"	48'1"	58'7"
CP 351700 - 351899	12'3&5/8"	48'1"	58'7"
CP 351700 - 352853	12'4"	48'1"	58'7"
UNPX 100000 - 100963	11'11"	52'4"	58'7"
UNPX 102000 - 102599	11'11"	52'4"	58'7"
UNPX 102600 - 102959	12'4"	48'1"	58'7"
CPHX 799632 - 799999	12'4"	48'1"	58'7"
New Bathtubs			
CP 350000 - 350285	11'7"	48'1"	58'7"
CNR Gondola Cars	Up to 11'10"	52'3"	58'7"

* Received from the CPR in October 1985.

accomplished using a continuous loading system where the trains move through a load-out facility at about 0.5 km/h (0.3 mph).

In order to load moving cars, the mining companies have developed a variety of techniques and load-out designs. The designs vary significantly from mine to mine. The standard procedure is for the mile long train to proceed through a mine load-out facility around a continuous rail loop. Not all mines employ a rail loop, certain operators load their trains on sidings parallel to the main rail lines. Cars are either pulled through a load-out by the motive power units or controlled on a declining grade.

To unload coal cars at the end terminals, the coal industry in western Canada employs the rotary dumping technique. The cars in coal train service are fitted with rotary couplings for use with rotary dumpers.

In 1982 there were three coal terminals on the west coast of Canada, all three were in Vancouver, and all employed rotary dumpers. Two of the three terminals, Roberts Bank and Neptune Terminals, had continous rail loops and automatic car-indexing to move trains through their dumpers. At the third terminal, Port Moody, trains were uncoupled and the coal cars shunted in groups into the dumper. Coal shipments via Port Moody were discontinued in 1983.

A new coal terminal on Ridley Island near Prince Rupert, British Columbia began operations in late 1983. A rail loop, tandem rotary-dumper, thaw shed and car-indexing system are employed at the Ridley Island terminal.

The coal terminal at Thunder Bay, Ontario has a rail loop, a thaw shed, a rotary dumper and an automatic car-indexing system.

Under ideal conditions the round trip travelling time for a coal train to cover approximately 2200 kms (1400 miles) from the southern B.C. coal fields to the west coast and back is 72 hours. The loading and unloading operations at either end add between three to four hours each to that round trip time for a total (again under ideal conditions) of approximately 80 hours. Under normal operating conditions however, delays, either during loading, unloading or en route, considerably lengthen the round trip time. Two of the Pacific coast coal terminals now employ tandem car dumpers. These double-dumping units reduce train unloading times at these two terminals.

3.2 Coal Production and Transportation Routes

In 1984 total Canadian coal production was approximately 57.4 million tonnes of clean coal (and lignite). Of that total approximately 26 million tonnes were shipped by unit train; the remainder was used either adjacent to mine sites or shipped over shorter distances, less than 100 km. Predictions as to the future production of clean coal in Canada vary, the general consensus is that production and exports will increase over the long term (Table 4). As a result of this expanded production the amount of coal shipped by train over long distances will also increase significantly.

Except for coal imported by ship from ports on the American side of Lake Erie most of the coal presently moved over long distance in Canada is moved in unit trains and the greatest portion of the coal shipped by rail for export is mined in western Canada either in British Columbia (Areas A and C in Figure 1) or in northwest Alberta (Area B in

TABLE 4 CANADIAN COAL PRODUCTION
(Metallurgical plus Thermal Coal)

Tonnes x 10^6					
1979	1982	1983	1984	1990*	2000*
33.0	42.8	44.8	57.4	66 to 75	92 to 182

* The source of the production estimates was the Coal Association of Canada.

Figure 1). The coal shipped to Vancouver from these open pit and underground mines along the British Columbia-Alberta border is transported in open-topped rail cars over rough terrain for approximately 1 100 km.

Coal has been shipped over the main rail lines through the Fraser Valley to Vancouver for decades, the quantity transported increased markedly with the opening of the Roberts Bank coal terminal in Vancouver in 1970. In 1984 over 1950 trains carried approximately 19.5 millon tonnes of coal through southern B.C. to the Vancouver coal terminals, Roberts Bank and Neptune Terminals.

Coal is also carried by rail from mines along the B.C./Alberta border to the Thunder Bay coal terminal through communities in Alberta, Saskatchewan, Manitoba, and Ontario (Figure 1); however, the volume of coal moved through these areas is considerably less than the amount shipped through the Fraser Valley. Approximately 2.1 million tonnes were hauled east by over 210 coal trains in 1984. The greater portion of the coal shipped east along this route was transhipped to lake vessels for transport to Ontario steel mills and power plants.

Trains also haul coal from mines in central Alberta, Saskatchewan, New Brunswick and Nova Scotia. In 1984, the larger rail shipments in these areas included over 0.5 million tonnes transported approximately 400 km from the Minto Area to Dalhousie in New Brunswick, and approximately 1.3 million tonnes of lignite transported over 1 000 km from the Estevan area of Saskatchewan to Thunder Bay, Ontario. Most of the larger volume coal shipments in Nova Scotia are by rail over short distances, less than 100 km.

In addition to the aforementioned coal transportation networks a major coal development located in the northeast of British Columbia began production in 1983 (Area C in Figure 1). Coal is shipped by rail from mines in this area to the new coal terminal at Prince Rupert, B.C. (Area D in Figure 1). The Prince Rupert (Ridley Island) terminal had an initial design capacity of 12 million tonnes throughput and coal shipments in 1984 were 5.3 million tonnes, with 7.3 million tonnes projected for 1986.

The discussions in this report concern large coal operations which transport their product by rail over long distances, however, it is recognized that the movement of small quantities of coal by truck, train, conveyor or barge, over short distances, may also result in local nuisance pollution from wind-blown coal dust. Although not directly applicable, the information in this document and the listed references may be of use to small producers addressing similar coal dusting problems.

3.3 Emissions of Fugitive Dust and Potential Coal Losses

Almost all of the coal shipped through the lower Fraser Valley to Vancouver is processed in coal wash plants and all but a small percentage, less than 5%, is thermally dried to reduce the moisture content prior to transport. This export coal is highly friable and has a high percentage of fines, 20% less than 60 mesh (250 micron) plus 7% less than 200 mesh (75 micron) in some samples (23). The quantity of fine coal present in bulk coal shipments is important because loose, exposed, fine coal on or near the surface of an open-top car is susceptible to wind entrainment.

With respect to fines content, there can be considerable variation between shipments from the same mine. It is speculated that higher moisture content combined with a smaller percentage of fines may account for the lack of fugitive dusting problems or complaints along coal/rail corridors in areas other than southern British Columbia.

It is difficult to predict the severity of dust emissions from an open-top rail car because of the many variables which can effect the emission rate. Some parameters can be measured such as car geometry, route length, coal fines content and coal moisture content, but others, which include the ambient weather conditions and the state of the coal surface en route, are difficult both to predict and to measure.

Prevailing wind and the air movement created by train motion are critical to the coal dust emission rate, since they combine to create complex air flow patterns over the coal surface which can entrain exposed fine coal particles. Field observations have shown that trains travelling at speeds in excess of 50 km/h (30 mph) in dry weather can emit significantly more fine coal dust than trains travelling at lower speeds (24). Laboratory wind tunnel tests measured threshold dusting velocities in a range of 30 to 40 km/h (18 to 25 mph) (13), similar threshold velocities were measured by other investigators using coal from the U.S.A. (25).

Under actual operating situations environmental parameters other than wind can also act either to mitigate or to increase coal dust emissions. For example, a train travelling at 100 km/h (60 mph) during a heavy rain storm will likely emit no coal dust

while trains travelling at 30 km/h on a dry day with high crosswinds have been observed to emit a "heavy" visible coal dust cloud. (12).

Several investigators attempted to measure coal loss from trains by weighing loaded cars before and after shipment. To date, all of these efforts have been unsuccessful (1), (3) and (26). The following excerpt (3) is a description of the difficulties encountered during one experiment: "Exact measurements of coal losses during transportation were difficult to determine with a high degree of confidence. Some problems experienced during the study included inconsistencies in weigh-scale calibration, variations of existing moisture content of the coal, addition of flying debris deposited in cars en route, and the inclusions of rain and/or snow."(3)

However, various researchers have estimated that when no coal dust control measures are employed, the maximum potential coal losses, for a one way trip of approximately 1 100 km (700 mi) over rough terrain during dry conditions, are in a range from 0.5 to 3% of the total coal load (2), (18), (25). Wind tunnel studies on scaled down rail car models and coal surfaces have provided emission factors within a range 0.9% to 1.76% of the total coal load in the car, i.e. within the same range as the emission factor estimates (13).

Theoretical estimates of coal losses have been attempted along with the associated economic values for the 19.5 million tonnes of coal shipped to Vancouver in 1984, based on maximum uncontrolled emission factors of 0.25, 0.5 and 1.0%, Table 5. It is evident that even at the low end of the emission range presented the uncontrolled dust loss would represent a potentially significant product loss. Potentially the loss of product provides some economic incentive for controlling wind-blown coal losses from trains. The coal producers in Western Canada do not agree with either the loss estimates or the dollar values displayed. They do not feel that up to $2 000 000 would be saved per year by reducing coal losses on the Vancouver coal shipments to zero. However, they have tabled neither data nor production figures to counter the theoretical estimates shown in Tables 5 and 6. Therefore, these estimates have been retained.

The estimates in Table 5 are for uncontrolled emissions whereas all of the major producers shipping coal to Vancouver employ sealant sprays to control coal dust emissions. The level to which the dust emissions from these trains were reduced by the surface coatings provided by these sealant sprays has not been quantified. However, assuming a crust retention average at the 85% objective (Section 3.8.1) for all trains and assuming that crust retention reflects a comparable reduction from uncontrolled losses, estimates were made of the theoretical emissions with dust controls in place, Table 6. A

TABLE 5 THEORETICAL DUST LOSS ESTIMATES - UNCONTROLLED EMISSIONS*

Estimated Uncontrolled Emission factor	Theoretical losses for a 100 car train		Maximum potential losses for 19.5 million tonnes of coal shipped through Vancouver (1984)	
(% of load)	Coal Lost (tonnes)	Economic Loss (at $70/tonne)	Coal Lost (tonnes)	Economic Loss (at $70/tonne)
0.25	25	$1 750	49 000	$3.4 x 10^6
0.5	50	$3 500	98 000	$6.8 x 10^6
1.0	100	$7 000	195 000	$13.7 x 10^6

TABLE 6 THEORETICAL DUST LOSSES - 85% CONTROL OF COAL DUST EMISSIONS*

Estimated Uncontrolled Emission Factor	Theoretical losses for a 100 car train with 85% Dust Control		Maximum potential losses for 19.5 million tonnes of coal shipped through Vancouver (1984) with 85% Dust Control -	
(% of load)	Coal Lost (tonnes)	Economic Loss (at $70/tonne)	Coal Lost (tonnes)	Economic Loss (at $70/tonne)
0.25	3.7	$ 263	7 400	$0.5 x 10^6
0.5	7.5	$ 525	14 700	$1.0 x 10^6
1.0	15	$1050	29 000	$2.0 x 10^6

* The coal producers in Western Canada do not agree with either the loss estimates or the dollar values displayed in these tables.

comparison of Tables 5 and 6 illustrates there is theoretically a significant economic benefit in controlling dust losses.

3.4 Coal Dust as a Nuisance Contaminant

Coal dust blown from trains is a nuisance pollutant and is not considered to be a hazard to human health. Even though dust concentrations in the vicinity of the railway tracks during the passing of "heavily" dusting coal trains can be high (over 5 000 μ gm/m^3 for a number of measurements using non-standard sampling devices)(4), these emission

A. LIGHTLY DUSTING LOADED COAL TRAIN

B. HEAVILY DUSTING LOADED COAL TRAIN

FIGURE 5 TRAIN PHOTOGRAPHS AGASSIZ, B.C.

incidents are brief, six to 10 minutes. A hazard to human health from repeated exposure to high level, short duration coal train dusting events has not been identified.

In an effort to determine more about the effect of coal dust on biological systems, Environment Canada commissioned a study to test four Canadian coal samples for possible mutagenic activity. The results of the study (9), and another similar study in the U.S.A. (27), were inconclusive. Fugitive coal dust from trains is still considered to be a nuisance contaminant.

The coal dust emitted by trains is comprised mainly of fine black particles which are carried by winds onto properties adjoining the railway tracks. This fine black dust will soil almost any exposed surface, adversely affecting the aesthetic appearance of property and clothing. Coal dust soiling complaints concern damage to curtains, drapes, decks, automobiles, lawn furniture, clothing, boats and cars. In Agassiz, B.C. expenditures have been and continue to be made by citizens to clean property which has been soiled by coal dust.

Since 1979 the complaints have come from the communities of Agassiz, Surrey and Kamloops, B.C. and have been directed to elected representatives, government agencies, railway companies, coal mining companies and to local newspapers (2). Two photographs of a section of track in Agassiz, B.C., one taken during the passing of a lightly dusting train and the other during the transit of a "heavily" dusting train, illustrate the problem, Figure 5.

In addition to residential nuisance soiling there is a potential for the cross-contamination of industrial products by wind-blown coal dust from trains. During the early planning stages of the recently completed northeast B.C. coal development operators of a pulp mill adjacent to the site of the Ridley Island coal terminal at Prince Rupert expressed concern about potential contamination of their pulp product by wind-blown coal dust from terminal activities and the operation of coal trains which would pass their property.

In the process of integrating proven control technologies into the design of the entire transportation system, the pulp mill company's concerns were recognized (18) and mitigation measures were installed as an integral part of the northeast B.C. Coal development. The results of an extensive en route dust monitoring study indicate that with respect to the Northern B.C. pulp producers involved, the mitigation measures employed in the rail transportation system have been successful in minimizing fugitive dust emissions (19). The pulp producers have not reported any cross-contamination problems. The results of an extensive dust monitoring program around Ridley Terminal

and Prince Rupert, and the success of the mitigative measures with respect to coal train dust control, will be presented in an upcoming report (20).

With respect to government legislation, there is no federal or provincial standard which applies specifically to the short-duration nuisance pollution incidents associated with wind-blown coal dust from trains. Existing air quality objectives for particulate matter established by various government agencies apply to total suspended particulates or total dustfall without regard to its composition or source. There are no specific air quality objectives for coal particles.

Standard high-volume sampler measurements of total suspended particulate from a provincial air monitoring station located 100 meters from the railway tracks in Agassiz, B.C. have been below the annual maximum "acceptable" standard of 70 $\mu gm/m^3$ since 1979. Occasional excursions of measured total suspended particulate readings to the 24 hour maximum acceptable level, 120 ugm/m^3, have been recorded. It is important to note however that because of the lack of an approved technique, no attempt has been made to analyze the coal dust fraction in these samples (see Section 3.7.2).

3.5 Pathways

The air currents over the surface of the coal load in a rail car are a combination of ambient wind and wind generated as a result of train motion.

The deposition distance for coal particles blown from trains will depend upon a variety of factors such as: coal car height, train speed, prevailing ambient conditions; (wind and precipitation) terrain obstructions, plus the size and specific gravity of the coal particles. Visible coal dust was reported by one observer (24) to carry at least 30 metres from the centre of the tracks. The Environment Canada coal dust monitoring station at Agassiz, B.C. has dust samplers located up to 50 metres from the centre of the railway tracks, and evidence of coal dust deposition has been found at those locations (4).

A study (6), commissioned by the Roberts Bank (BC) Expansion Railway Committee, reporting on the results of rail-side dust monitoring studies found that, "... the major (dust) impacts from present rail operations are likely to be contained within a zone of 150 metres on either side of the tracks," and ".. that most, if not all, of the coal dust falls out within 160 metres of the tracks". Based upon experience in western Canada it would appear that the area of primary exposure to wind-blown nuisance coal dust from unit trains is within 200 meters of the railway tracks. Homes in Agassiz and in other communities in southern British Columbia are located within 40 metres of the railway tracks.

3.6 Environmental Concerns

The rail corridor from the coal fields of southern B.C. to Vancouver passes through many small communities. Between 1970 and 1975 complaints about fugitive dusting from coal trains were received from a number of these communities including, Kamloops, Agassiz, Delta, Surrey and the Cranbrook area. Since the advent of sealant sprays in 1975 the number of complaints have declined, those received have come from Agassiz, Surrey and Kamloops, B.C. and are associated with the CNR and CPR rail corridors.

Since 1975 there have been only a limited number of complaints about fugitive dusting associated with coal shipped by rail from mines in northwest Alberta via CN lines along the Fraser Valley to tidewater terminals at Vancouver, B.C. One mine has reported to have received "two complaints in the last four years" (28).

The area from Hope to Vancouver appears particularly prone to fugitive dusting. This section of the rail line is near the end of the long coal-rail journey from mine to terminal and many of the surface sealing coatings on loaded rail cars may have fractured or broken as a result of vibration and shock experienced en route. Much of the terrain along this section of the route is also flat and trains frequently travel at or near the maximum allowable track speed (80 km/h). High natural crosswinds, particularly in the Agassiz area, combine with train generated winds to create high, turbulent, dust-entraining air currents over coal cars.

The recently opened coal/rail corridor in northern B.C. from Tumbler Ridge to Prince Rupert not only passes through many small communities, but it also passes by several pulp and paper operations. The sensitivity of certain pulp and paper operations to possible product contamination by wind-blown coal dust from coal trains was first addressed in connection with the Ridley Island coal terminal construction (18) (see discussion section 3.4). The companies are concerned that coal dust could deposit wood chip storage piles and end up as black particles in the final pulp. Recognizing the potential for both cross-contamination of industrial products and residential nuisance pollution as a result of this coal movement, the Northeast Coal Technical Committee on Coal Dust was established to address possible dusting problems from trains using this route. Before the first coal shipments began in late 1983 the Committee had instituted a background dust monitoring study to collect total suspended particles at 15 sites along the corridor. Comparisons of dust measurements made before and after the start of coal train traffic will provide a means of assessing exposure to coal dust emissions (19), (20).

Coal dust mitigation measures in the form of dust suppressant sprays were installed at the mine sites. To date, the operation of coal trains along this northern rail corridor has resulted in one public complaint about fugitive dusting in the Terrace, B.C. area. The pulp and paper firms have not reported any coal particle contamination of their pulp products.

As shown in Figure 1, coal is transported by rail through communities in provinces other than British Columbia, however, British Columbia is considered the principal area of population exposure to this form of nuisance air pollution, principally the communities in the lower Fraser Valley. For coal shipped east from Alberta and B.C. to Ontario there have also been only a limited number of complaints about fugitive dusting. The higher moisture and lower fines content of Saskatchewan lignite are thought to be factors in limiting coal train dust emissions from shipments originating in that province.

In Nova Scotia, short transportation distances combined with high moisture content are thought to limit dust emissions en route. Similarly no problems have been reported in New Brunswick.

3.7 Coal Dust Sampling and Analytical Methods

In order to assess the extent, severity and persistance of an air contaminant it is desirable to measure both emissions at source and air quality at points of impact. Because of technical difficulties and budget constraints the measurement of on board dust emissions from a 100 car train have not been attempted to date. Attempts have been made however to measure the quantity of coal dust emitted from trains at specific points of impact using a variety of instruments. The methods used and the results obtained are discussed below.

3.7.1 Particulate Sampling at Point of Impact.

Two types of air quality sampling were attempted, episode and long term. Episode monitoring, the collection of coal dust from single trains, was thought desirable in order to quantify the dust emissions from specific trains as well as to assess the effectiveness of the dust control measures employed by a specific coal mine. Long term monitoring was required in order to better evaluate overall trends in nuisance dusting and to ascertain whether improved dust control techniques were required.

The dust emissions from a moving "heavily" dusting train when viewed from a fixed sampling point are of high intensity and last only a few minutes. These unique characteristics present problems when using conventional particulate sampling devices to

collect particulate from the trains. Also, qualitative analysis techniques for coal in collected particulate samples are still in the research stage, therefore it is not possible to reliably separate coal from background dust in collected samples.

A. Long Term Trend Monitoring

Various investigators experimented with a variety of conventional sampling methods for rail-side long-term trend monitoring including high-volume, low-volume, soiling index and dustfall samplers (4), (5), (6), (12), (14), (22). Optical particulate counters were also employed (7), (8), (14). None of these devices fulfilled all of the requirements of a monitoring system for measuring long-term trends for coal dust from trains.

The standard dustfall jar was used for trend monitoring at Agassiz and apart from visual observations, dustfall results provided the most complete set of trend data (4). However, this device lacked versatility. Its long sampling interval, approximately one month, limited its application.

Low-volume samplers were field tested by both the British Columbia Ministry of the Environment and Environment Canada (14), however, for this application the volume sampling rate of this device was too low. Its very low sampling rate limited the quantity of particulate it could collect during the brief dusting events.

There has been a renewed interest in the conventional soiling index device (the COH tape sampler) as a trend monitoring instrument. The British Columbia Ministry of the Environment conducted field experiments with this particulate sampling instrument, however this device also suffered from too low a sampling rate. Difficulties were also experienced in matching collected samples to dusting trains (14).

The high-volume sampler was also used as a trend monitor. However, a hi-vol's highest collection efficiency is for particles of less than 30 microns. Since one investigator has reported that 93 and 95%, by weight, of the particulate collected from loaded coal trains (using the coated-plate technique) is larger than 20 micron in diameter (6), the large size fraction of settleable nuisance coal dust may not be captured by the conventional high-volume sampler. Consequently the sampler does not provide an appropriate method for assessing nuisance soiling caused by coal dust fallout.

B. Short Term Episode Monitoring

Most conventional ambient-particulate collection devices also appear unsuited for short duration episode or event monitoring applications. For example, experiments

have shown that when used in its standard configuration for short episode monitoring the high-volume sampler suffers from an inability to collect sufficient particulate mass and, as in the trend monitoring case, the approximately 30 micron upper cut-off appears to restrict from capture the large coal particles which can contribute to nuisance soiling.

The conventional dustfall sampler captures all settleable particles but does not capture smaller size fractions which remain airborne and although this device collects all settleable particulate, the small collection area does not allow sufficient mass to be collected from its exposure to a single dusting train.

Conventional samplers have proved inadequate, but several experimental particulate collection systems have proved reasonably successful in monitoring individual train emissions. The devices or methods tested include: a series of coated horizontal plate collectors (6), (12) and (29), and a modified high-volume sampler (4). Both of these devices appear to be capable of collecting sufficient particulate matter from a single dusting event, but unfortunately both techniques are labour intensive and require an operator on-site during each event to be measured.

Aerosol monitors employing the light scattering technique have been tested for episode monitoring (7), (8), (14). These devices do not necessarily require an on-site operator, but there can be no after-espisode sample analysis for coal dust since they do not collect a particulate sample. Light scattering instruments employed in the conventional configuration are also insensitive to particles larger than 20 micron in diameter (7). Although light scattering devices are not a recognized reference method for ambient coal dust monitoring, a researcher has reported success in correlating track side dust measurements using a light scattering device (that was modified to count particles greater than 20 micron) to observed levels of visible dusting (8).

3.7.1.1 Settleable Particulate Trend Monitoring Results. Standard dustfall jars have been employed at the Environment Canada Agassiz monitoring site since 1979. The Province of British Columbia employs a dustfall objective of 1.7 to 2.9 mg/(dm^2. day). The results from the four Environment Canada dustfall samplers at Agassiz when compared to this provincial standard are summarized in Table 7 (4).

The four dustfall jars at the Agassiz monitoring station were close to the railway tracks (within 50 m). However, the frequent occurrence of dustfall levels greater than 2.9 mg/(dm^2.day) could not be confirmed as originating primarily from coal trains without an accurate method of analyzing for coal dust. At certain times of the year high winds were common in Agassiz, therefore background dust other than coal would

TABLE 7 AGASSIZ DUSTFALL READINGS COMPARED TO B.C. STANDARD

Dustfall Monitor	Sept. 79 to Apr. 83 Total Readings	Number of Dustfall Readings Which are			
		Below 1.7	Within 1.7 to 2.9 Range	Above 2.9	Percent Above 2.9
N1	30	14	6	10	33
N2	27	13	6	8	30
S1	27	12	7	8	30
S2	27	7	9	11	41
Number of Readings	111	46	28	37	33%

* The B.C. Provincial objective for total dustfall is 1.7 to 2.9 mg/(dm^2·day).
N1 = 18.6 meters north of the tracks. S1 = 24 meters south of the tracks.
N2 = 41.8 meters north of the tracks. S2 = 50 meters south of the tracks.

contribute to dustfall loadings (4). However in five years of dust monitoring, all but one of 12 incidents where the dustfall readings exceeded 10 mg/(dm^2·day) were registered by the two dustfall jars closest to the railway tracks (N1 and S1 in Table 7). This suggests that coal dust emissions from coal trains along with reentrained track dust from all passing trains were causing the elevated dustfall levels at the sites closest to the tracks.

3.7.2 Coal Analysis. As noted earlier, a satisfactory qualitative analysis method for coal in collected dust samples is necessary before coal dust impacts can be measured in proper scientific terms. A scientific assessment of the effectiveness of dust-control measures also requires a proven coal analysis method.

Conventional particulate samplers collect all of the particulate matter in a certain size range and therefore simple gravimetric analysis alone will not quantify particulate loading due to coal dust. The coal fraction of collected particulate samples is required in order to accurately assess coal dust impacts, particularly when samples have been collected over longer sampling intervals. Research projects sponsored jointly by the B.C. Ministry of Environment and Environment Canada, evaluated several of these new methods, including the optical microscope, the electron microscope and the chemical mass balance technique (14). Research into the applicability of a computer controlled scanning electron microscope for coal analysis in suspended particulate samples was sponsored by the northeast coal companies (19). These new methods show promise in

being able to measure the amount of coal in collected samples, but none of the methods have yet proven to be sufficiently reliable to be used for this application. The high cost of individual sample analysis and the need for specialist laboratories are further drawbacks to using these methods routinely.

3.8 Performance Assessment

Coal dust from trains is a nuisance pollution problem and as such subjective judgement is necessary in order to assess acceptable levels of nuisance. As noted in Section 3.7, establishing a coal dust collection method and an acceptable coal qualitative analysis technique will simplify the assessment process, but a certain degree of subjective assessment of nuisance levels will always be required. This requirement for subjective judgement makes it difficult to establish specific dust emission performance goals for coal trains.

At present, fugitive dust emissions from trains are assessed by observing visible dust from individual trains (Section 3.9) and the performance of dust-control systems are monitored by the measurement of surface coating, or crust, remaining on loaded cars at the end terminal. Although these two techniques have drawbacks they provide the only means currently available for assessing dust emissions and performance.

3.8.1 Crust Retention Measurements. Once sealant sprays had been selected as the preferred dust control technique, there was a need to assess system performance. Lacking proven quantitative sampling methods and qualitative analysis techniques for coal dust, the initial investigators, seeking solutions to the fugitive dusting problem, moved away from a performance measurement approach that relied on ambient air sampling to one that relied on measuring the coal surface of loaded cars (arriving at the unloading terminal) still covered by a dust-sealing surface-coating (as sprayed at the coal mines) (2). It was generally agreed that when a large surface area was covered (or more crust retained) it resulted in a corresponding reduction in the coal dust losses en route and in turn, this provided an indication of the effectiveness of dust control or control system efficiency.

One difficultly with the crust retention dust assessment technique, from a regulatory and enforcement perspective, is that although emissions are reduced by increased crust retention it is not known if dust emissions are reduced in direct correlation to the crust retention increases. However, it is generally accepted that ambient air quality en route will be improved in relation to increased crust retention on rail cars.

Another drawback to this technique of performance assessment is that crust-retention measurements are time consuming and manpower intensive. Personnel are required at the unloading terminal to observe, estimate, and record crust performance. As a result individual train crust retention assessments are usually derived by measuring the crust retentions on only 20 to 30 cars within a particular train and projecting the average of these measurements to the crust retention average for the entire 100 car train.

In spite of these limitations, until an alternative technique is developed, the crust retention method will continue as the means of assessing control-system performance.

3.8.2 Results: Crust Retention Studies. Experiments with sealant chemicals in the early 1970's concluded that a crust retention goal of 85% coverage, on each car when measured at the unloading terminal, was practical and attainable. The participants in those studies, which included all the large coal shippers in Western Canada at that time, agreed to the 85% crust retention goal. The researchers also predicted that crust retentions of 90% and higher could be achieved once more experience was gained in operating the spray systems (2).

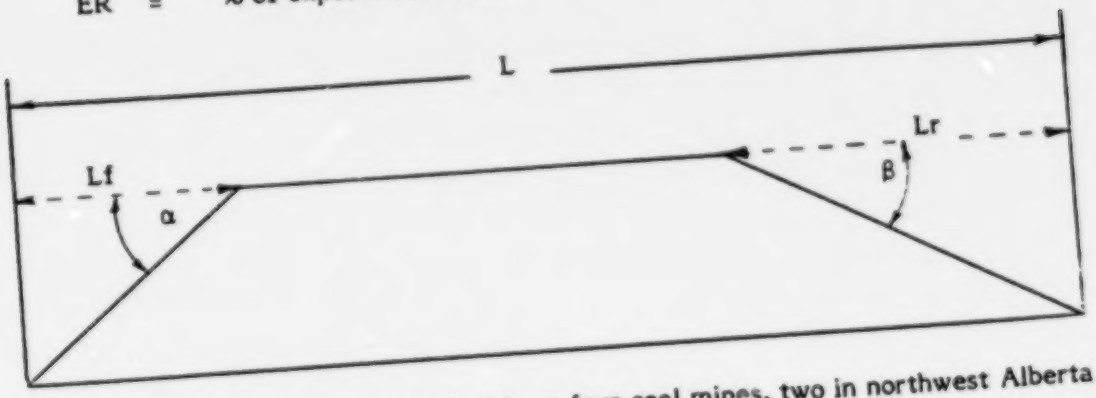
In connection with the investigations reopened in 1979, Environment Canada personnel in 1981 checked a small number of trains at two Vancouver coal terminals and found that the 1975 crust retention goal of 85% was not achieved on the trains assessed (22).

Subsequently, in 1982, Environment Canada, in conjunction with the Province of British Columbia and with the cooperation of the coal industry, commissioned a more extensive study. The object of the investigation was to assess the performance of the existing dust control systems and to attempt to establish reasons for the persistence of fugitive dust emissions from coal trains in southern British Columbia. The surface crust-retention on over 1300 coal cars in 47 unit trains (as they arrived at either of two coal terminals in Vancouver) were examined by observers and the results reported with respect to the percentage of the top surface of each of these cars still covered by dust suppressant crust.

The crust retention on each car checked during the study was calculated according to the following formula:

The percent crust remaining or retained is $\%CR = 100 - \left[(Lf/\cos\alpha)(\%EF) + (L - Lf - Lr)(\%EC) + (Lr/\cos\beta)(\%ER)\right] / \left((Lf/\cos\alpha) + (L - Lf - Lr) + (Lr/\cos\beta)\right)$

where: CR = % of crust retained on the surface of each coal car
EF = % of exposed front area
EC = % of exposed centre area
ER = % of exposed rear area
Lf = Front length
Lr = Rear length
L = Total car length



The trains examined originated from four coal mines, two in northwest Alberta and two in southeast B.C. The results of this coal car survey, illustrated in Tables 8 and 9, confirmed that during this period the over-all crust retention averages for the trains examined were less than the 85% goal (12).

TABLE 8 CRUST RETENTION PERFORMANCE BY COAL MINE

Mine	No. of Cars Examined (P)	Average Crust Retention (%) for (P) Cars		
		F*	C*	R*
A	120	51	98	42
B	348	49	88	36
C	446	72	94	20
D	460	51	94	27

* F - Car Front Slope
* C - Car Centre Profile
* R - Car Rear Slope

Note: - All trains were sprayed with latex-based products.
- One mine was not employing normal loading procedures.

TABLE 9 CRUST RETENTION - 85% GOAL

Mine	Number of Trains Examined (N)	Crust Retention		Number of Trains With Crust Retention Average		
		Average (N) Trains (%)	Range (%)	≤ 75%	75% to 85%	≥ 85%
A	4	81	78 to 83	0	4	0
B	12	78	36 to 95	4	3	5
C	16	77	50 to 89	6	7	3
D	15	75	55 to 98	9	3	3

Note: - All trains were sprayed with latex - based products.
- One mine was not employing normal loading procedures.

During this survey, September to November 1982, there was a factor which may have influenced crust retention averages at one mine. This particular mine was operating in a slow-down mode. Since the loading, profiling and spraying operations at that mine were not consistent with normal operations, the crust retentions on the cars loaded and sprayed by that mine may also have differed from the norm.

Of all trains observed during the study, only 24% (11 of 47) had crust retention averages assessed as equal to or greater than the 85% crust retention goal. When the train averages were grouped by mine and subsequently averaged, it was found that all of the averages for the N trains from each mine were also below the 85% goal, Table 9. A subsequent re-evaluation of the raw data from the crust retention study confirmed these results (30).

The range of train crust retention averages illustrated shows that during the study all four of the mines had serious problems achieving consistent performance. With the exception of mine A (where only four trains were available for inspection during the trial period), the three remaining mines registered a number of "very good" trains, with projected average crust retentions greater than 85%. However, all mines also had an equal or greater number of "poor" trains, assessed at less than 75% average crust-retention. For example, Mine B had five trains assessed at greater than 85% average crust retention, and had four trains assessed as less than 75% crust retention. Two of the latter were assessed at less than 50% average crust retention. Additional discussion of the results of this study can be found in section 4.1.

These results indicate that although spray systems are capable of coating trains with dust suppressant coatings which have a high crust retention, on occasion the coatings provided by the same spray systems may be inadequate for dust control purposes. Crust retention variation within individual cars is also revealed by the survey results, Table 8. The reasons for higher crust retentions on the flat central portion of the coal cars are discussed in section 4.3.

Again, note that caution must be exercised when interpreting crust retention averages. Crust retention measurements are made on a number of individual coal cars examined at the end terminal, whereas average performance ratings are projections for an entire train, or are combined averages for a number of coal trains from the same mine.

Regardless, the field study results indicate that chemical spray systems may fail to consistently provide adequate crust retention. The lack of consistency is a serious problem since several poorly sprayed, dusting cars within a single train set of generally well sprayed cars can create a dusting problem en route. A few unsprayed cars can void the otherwise good performance of the well sprayed cars.

The overall objective of all this work is to eliminate heavily dusting trains. Depending on weather conditions, an average crust retention of 85% per car generally appears to achieve this objective. In warm but not too dry weather a crust retention in the 70% range may be sufficient to limit emissions to light visible dust emissions only (8). However, during weather conditions which are more conducive to fugitive dust generation, i.e. hot and dry, 70% crust retention may not be sufficient to prevent "heavy" nuisance dusting.

Only 100% crust retention can completely eliminate fugitive dust emissions. Although it is difficult to set a lesser standard that will satisfy all objectives, Environment Canada still considers a goal of 85% crust retention on each car to be the minimum requirement. In 1979, after four years of spray system operation at one mine, one researcher felt that because of the loading configuration adopted by the company, "a 90% retention of chemical binders is easily attainable" (3). The success of certain mines in western Canada in achieving higher crust retention averages indicates that the 85% crust retention is a practical performance goal for all mines for this form of dust control technology.

The Environment Canada field study (12) also included the assessment of the surface coatings on over 350 coal cars sprayed with experimental sealant chemicals or formulations. The performance results for some of these new chemicals were encouraging and subsequently several coal mines switched to chemicals other than latex.

3.9 Visual Observation of Coal Trains

An assessment of the severity of individual train dusting incidents can be made by observers recording visible dust emissions. This technique has been successfully employed at the Agassiz monitoring station with observers classifying coal trains as either "heavy", "medium", "light", "very light", or "not" dusting (4).

However, even though the visual observation technique provides a direct indication of the severity of train dusting, there are difficulties with respect to its application. One problem is the need for subjective judgement. Trains assessed as "medium" and "heavily" dusting are usually obvious even to an inexperienced observer, but differentiation between incidents judged "light", "very light" and "none" can be controversial. Other problems with the technique include: difficulty in assessing trains travelling at night, variations in assessed dusting levels between observers, and the apparent contradiction when trains assessed as having no visible dust emission are judged to be sources of soiling dust. The latter difficulty arises because very fine coal dust not visible to an observer may still carry from a train and settle on property to cause nuisance soiling.

However, experience has shown that trains assessed at the upper end of the visible dusting range, i.e. as "medium" and "heavily" dusting, are known sources of nuisance soiling and are very easily differentiated from light or non-dusting trains. The visual detection of these more severely dusting trains is one of the most rapid methods of reporting obvious cases of dust control system performance failures to the coal mining companies. The results of six years of train observations at the Agassiz monitoring site are discussed below.

3.9.1 Visible Dusting Results. Environment Canada has maintained a dust monitoring station in Agassiz, B.C. since 1979. A summary of the visual observation of coal trains passing that site is presented in Table 1.

It is important to note that although investigations have centered on the problem of visible dust emissions from loaded trains, each year a small number of visible dusting incidents have been recorded for "empty" trains travelling east through Agassiz. Dust emitted by "empty" trains appears to result from unemptied coal in the bottom of cars or from coal which clings to the external surfaces of a car after dumping. This is discussed in more detail in section 4.7.

For loaded coal trains, the percentage of visible dusting incidents (as compared to the total number of loaded coal trains observed) declined from 1980 to 1983, but

showed a marked upswing in 1984, Table 1 (4). The improvement from 1980 to 1983 appeared to reflect the greater attention given to the coal dust problem by the Federal/Provincial governments and the coal industry. The reasons reported for the increase in visibly dusting trains in 1984 included: two new mines with inexperienced personnel coming on-line in southeast B.C.; a major sealant product failure at two other mines; and chronic freezeup problems which affected the sealant application at one mine site and the washing of empty cars following the dumping process at one coal terminal.

Caution is advised in interpreting the trends revealed by the visual observation results since the Agassiz monitoring station is only manned on a part-time basis and it was not possible to check all of the coal trains passing the Agassiz monitoring site each day. Each day a number of visibly dusting and non-dusting trains may not be detected. This is especially important for trains travelling after dark. There has been a speed restriction on "heavy" dust emitting trains, but this restriction is adhered to more during daylight hours than after dark (4), (24).

The yearly train observations, Table 1, illustrate trends with respect to fugitive dusting in Agassiz, B.C., but they do not reveal another important aspect, the short-term inconsistencies in dust control performance at individual mines and coal terminals. For example, the breakdown of spray equipment at one mine can result in a number of dusting incidents being bunched together over a shorter time interval. The observed visibly dusting and heavily dusting trains for each month during 1983 and 1984 are illustrated in Table 10.

In 1984 the percentage of visibly dusting loaded trains to total trains observed varied from zero during three months to highs of 39, 39 and 45 percent during three others. In 1983 the extremes were less severe from 2% to 27%. Correspondingly, in 1984 the percentage of heavily dusting trains varied from zero during six months to highs of 20 and 23 percent for two other months, Table 10.

Observations in Agassiz have revealed that a single "Heavy" visibly dusting loaded or empty coal train can be a source of nuisance soiling, therefore a number of such trains passing through the community in a short period, i.e. a week or a month, such as happened during January and July, 1984 invariably leads to unacceptable dusting and public complaint.

After what appeared to be an improvement in overall dust control and a reduction in "heavy" dusting trains incidents in 1983, a reversal occurred in the first month of 1984. In January 1984 observers recorded the highest number of "heavy" dusting trains, 7, for any single month since inception of train observations in 1979. The

TABLE 10 OBSERVATIONS, AGASSIZ, 1983-84

Loaded Coal Trains - Agassiz
Visual Observations

Year	1983					1984				
	Total Trains Observed	Visibly Dusting No.	%*	Heavily Dusting No.	%**	Total Trains Observed	Visibly Dusting No.	%*	Heavily Dusting No.	%**
Jan	21	2	10	1	5	31	12	39 (c)	7	23 (c)
Feb	16	4	25	1	6	30	2	7	0	0
Mar	17	2	12	1	6	40	0	0	0	0
Apr	36	4	11	2	6	31	0	0	0	0
May	41	5	12	0	0	40	3	8	1	3
Jun	42	1	2	0	0	46	1	2	0	0
Jul	25	1	4	0	0	49	22	45 (s)	10	20 (s)
Aug	41	5	12	1	2	46	18	39 (s)	3	7 (s)
Sep	42	4	10	1	2	55	10	18 (s)	3	5 (s)
Oct	32	4	13	0	0	53	3	6	0	0
Nov	35	3	9	1	3	16	0	0	0	0
Dec	15	4	27	3	20	28	8	29	2	7
TOT.	363	39	11	11	3	465	79	17	26	6

Note: (c) Loading crew problems reported; (s) - Sealant chemical problems reported.

Empty Coal Trains - Agassiz
Visual Observations

Year	1983					1984				
	Total Trains Observed	Visibly Dusting No.	%*	Heavily Dusting No.	%**	Total Trains Observed	Visibly Dusting No.	%*	Heavily Dusting No.	%**
Jan	20	0	0	0	0	26	7	27	2	8
Feb	22	1	5	0	0	30	0	0	0	0
Mar	20	0	0	0	0	26	0	0	0	0
Apr	34	0	0	0	0	20	0	0	0	0
May	45	0	0	0	0	22	1	5	1	5
Jun	35	0	0	0	0	30	0	0	0	0
Jul	14	0	0	0	0	31	3	10	2	6
Aug	29	1	3	0	0	26	1	4	1	4
Sep	21	0	0	0	0	16	0	0	0	0
Oct	18	0	0	0	0	28	0	0	0	0
Nov	15	0	0	0	0	5	0	0	0	0
Dec	13	1	8	0	0	17	4	24	2	12
TOT.	286	3	1	0	0	277	16	6	8	3

* (Total Visibly Dusting Trains/Total Train Observations) x 100
** (Heavily Dusting Trains/Total Train Observations) x 100

percentage of visible dusting incidents to total observations for that month was also high (Table 10). In addition, the number of dusting incidents recorded for "empty" trains during January 1984 exceeded the entire number of "empty" train, visible dusting events recorded for all of 1983. Another high in "empty" train dusting events also occurred during July, 1984.

Chemical formulation problems at two large mines, spray equipment malfunction, spray system freeze-up, plus inexperienced personnel operating equipment at two new mines were cited by the coal producers as reasons for the inconsistent dust control performance by coal mines in southeast B.C. during 1984. Break-down of the car wash at one coal terminal was cited as one possible reason for the increase in "empty" dusting trains illustrated in Table 1.

4 SPRAY DUST CONTROL SYSTEMS - OPERATIONAL PROBLEMS AND SUGGESTIONS FOR IMPROVING PERFORMANCE

The chemical spray method of dust control is the system adopted by all of major coal producers in western Canada who ship coal over long distance by train. Sealant chemicals once applied form a solid crust or contiguous flexible layer over the surface of the coal load in a rail car thus preventing fine particle wind entrainment and hence fugitive dusting.

The facilities for applying chemical sealants, as installed at the western Canada coal mines, comprise storage tanks for the chemicals, mixing tanks or in-line mixers, pumps, valves and one or more swing-out spray headers (Figure 6). The tanks and pumps are located in a heated shed while the spray headers and connecting piping are located outside and are usually equipped with freeze protection for cold weather operations. The spray headers, which may comprise a number of separate spray bars and nozzles, are designed to pivot out of the way of engine units and other train components. Most of the mines have also installed coal profile-levelling devices as integral parts of the dust control systems. The chemical sealant spray systems were first installed in western Canada in the mid-1970's. Since their installation the coal mining companies have conducted numerous experiments with different chemical sealants, application methods and loading techniques.

Dusting incidents have significantly declined following the installations of spray systems in the mid - 1970's, but the dust control performance of the spray systems installed at certain mines has been inconsistent and unreliable. For example, there has been little or no public complaint about fugitive dusting from communities along six of the seven western coal-rail corridors illustrated in Figure 1. Virtually all of the public concern has focussed on dust from unit trains originating at mines in southeast B.C. carrying coal via the CPR line to Vancouver.

The intermittant spray system performance failures observed over the nearly 10 years of spray system operation appear to result from various problems associated with system design and operation.

Dust control performance failures occur when the chemicals sprayed over the coal surface at the coal mines fail to provide or to maintain a complete crust or coating over the coal surface during the trip to the end terminal. Historic records of observations at the tidewaters terminals in the early 1980's reveal the following surface crust deficiencies: little or no crust covering the front and rear end slopes; uncovered strips up

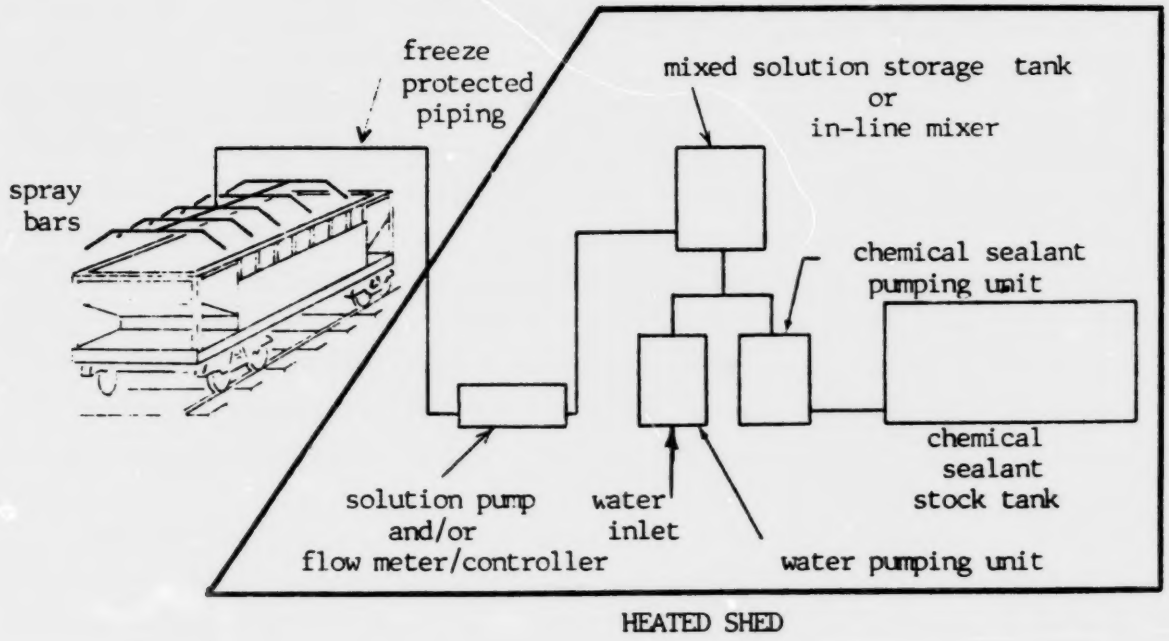


FIGURE 6 GENERALIZED SCHEMATIC OF A CHEMICAL SPRAY INSTALLATION

to one half a metre wide down the sides of the cars; deep uncovered gouges in the centre of the surface profile; alternating strips of covered and uncovered coal along the top of the load; or an entire car surface that had not been sprayed. With respect to gouged profiles, the coal producers report that contrary to these early observations, it is now common practice to spray cars after load corrections have been made.

Observation has indicated that the frequent occurrence of exposed coal surfaces in cars which have been sprayed with sealant chemicals may result from one or more of the following factors:

- poorly designed spray apparatus. Incomplete mixing or incorrect spray timing can result in incomplete coverage of a coal car surface or the uneven application of spray solutions;
- inadequate maintenance procedures at the mine site which results in plugged or inoperative spray nozzles, incorrectly aimed spray nozzles, frozen lines, or total equipment malfunction;
- the application of a sealant chemical at a concentration insufficient for producing stable surface crusts for the ambient conditions at the time of shipment;
- the selection and use of a sealant chemical product incapable of producing a crust or surface coating which will withstand the rigors of the journey;
- insufficient operator training which results in operator error and unsprayed surfaces;
- weaknesses inherent in the sealant chemical spray technique; or
- an inadequate load levelling device.

Insufficient crust retention on steep end slopes was noted during the original tests in the early 1970's and remains the most common problem (2), (12), (22).

In spite of these many problems, operating experience and the previously discussed studies verify that when properly operated, spray systems can achieve high crust retention levels with a resultant significant reduction in fugitive coal losses. As spray equipment is now in place at all coal exporting mines in western Canada, it is likely that this method of dust control will remain the industry preferred dust abatement technique.

Further research is needed to develop the optimum operating parameters for spray systems, however observation and experiment to date combined with the success achieved by many coal mines shows that standardization and improvements (where fugitive dusting is a problem) should result in adequate dust control.

4.1 Chemical Sealants

The physical-chemical characteristics of a chemical sealant such as wetting characteristics, phase separation and viscosity will determine a chemical's ability to form a stable crust or coating.

Some dry coal exhibits a poor affinity for water, therefore manufacturers normally add surface active agents to their formulations to improve the wetting characteristics and surface penetration. Laboratory and field tests have shown that most sealants do not adhere to sloped surfaces as well as they do to flat surfaces. One explanation for this failure is related in part to the wetting characteristics of the chemicals and to the simple fact that the solution will run off steep slopes. Oil and oil-based sealants have demonstrated good surface penetration on both flat and sloped surfaces.

Products with inferior mixing/emulsifying chacteristics periodically cause phase separation problems which can result in poor quality crusts by delivering inconsistent solution concentration at the point of application. Variations in spray solution concentration throughout a batch can result in surface crusts of varying strength throughout a single coal train, therefore thorough mixing of spray solutions is essential.

The flow properties of a spray solution or emulsion are affected by the viscosity characteristics of the chemical sealant. Increased viscosity at below freezing temperatures can result in frequent plugging of the spray nozzles. Difficulties with nozzle plugging have been reported for both asphalt-based and latex-based sprays.

One asphalt-based sealant was unacceptable to the railway company hauling the coal because the viscous emulsion caused excessive fouling of the rail car exteriors and braking components.

The first comprehensive series of tests and observations of spray system performance were conducted in 1974. The tests, described in Reference 2, were joint studies carried out by government agencies, the CPR and two of the large coal producers. Eight chemicals were evaluated during that study and their performances were assessed using the crust retention technique. Of the chemicals tested oil and oil-based emulsions were judged the most effective because of their crust regenerative properties. Latex based chemicals were as effective as oil emulsions on flat surfaces but frequently failed to remain intact on end slopes.

However, none of the chemicals tested provided a crust that would stay intact and cover 100% of the coal surface on every car for the entire journey from coal mine to end terminal. Some degradation was anticipated and for this reason 85% crust retention

was agreed to by the coal mining companies as the initial system performance goal. The investigators predicted that once new sealants, application techniques, and loading methods were perfected, crust retention averages of 95% and higher would be achieved (2). As discussed in Section 3.8.2, the higher crust retention averages have not been achieved and 85% crust retention remains the agreed upon goal.

Since 1975, in attempts to improve dust suppressant performance and to optimize costs, coal shippers have experimented with and in some cases switched to new chemicals or new formulations of older products. In the summer of 1980, only two types of chemical sealants, asphalt and latex emulsions, were in regular use, and by July 1981, the one firm spraying the asphalt emulsion switched to a latex spray. From August, 1981 to January, 1983, latex-based chemical sealants were the only type of chemical spray employed by the western Canada coal mines on a regular basis. In 1983, in search of more effective chemicals, several coal shippers shifted away from latex products and began using or experimenting with asphalt-based or polyacrylamide products. A list of many of the products which have been used, or tested, as dust suppressants is presented in Appendix B (31).

In 1981, because of the predominance of latex-based sprays and the apparent continuing problems with those products, Environment Canada commissioned a study to evaluate latex spray performance. The experiments were performed in a laboratory on shaker tables and in wind tunnels. High costs had precluded full scale, in-situ testing. Test results confirmed several known or suspected adverse traits of the latex-based chemicals which were on the market at that time (10):

- latex spray crusts did not adhere to slopes or irregular surfaces as well as they did to flat surfaces;
- to achieve maximum success on a sloped or irregular surface the chemical solution should be applied over the entire surface. Partially coated surfaces were easily undermined, undermined crusts failed uncovering the untreated coal below;
- the length of time a crust cured and the ambient conditions during the curing period influenced crust strength;
- latex sprays normally formed brittle crusts which were easily broken by shocks and vibrations during simulated train movement; and
- the concentration of the applied emulsion influenced crust strength.

The inability of most dust suppressant products to produce crusts that will adhere to steep end-slopes in loaded cars has been reported by almost every researcher

who has investigated surface coating performance (2), (10), (12), (22). However, in spite of ten years experience using chemical sprays, a practical solution to the end-slope retention problem has not been found. Reducing the length and angle of incline of end slopes through improved load levelling has been the best approach to resolving the crust failure problem.

The weathering of surface coatings en route is also a problem. Coal trains operate all year round and typically a train takes between 36 to 40 hours to make the trip from a mine on the BC/Alberta border to a tidewater terminal in British Columbia. Frequently, loaded coal trains are subjected to longer exposures to weathering because of delays en route. Degradation of a surface coating as a result of ambient weathering can reduce the dust abatement effectiveness of the coating.

The effect of weathering on surface coatings was demonstrated during a recent performance evaluation (12). For ten of the twelve trains originating from one mine (Mine B, Table 8) the lowest recorded crust retention was 71%; however the crust retention averages for the other two trains from that mine were 36 and 44%. One explanation for this substantial difference was that the two trains with the low crust retention averages had been held on sidings in the B.C. interior subject to weathering for about three weeks prior to completing their journey. This prolonged exposure is not normal, but such severe weathering could have been the cause of the crust deterioration noted on these two trains.

New dust suppressant products or new formulations may be capable of overcoming some of the problems noted above. Some of the preliminary results from new chemical tests are encouraging, however, the failure of a spray system to achieve more consistent and more complete dust abatement cannot be attributed solely to the inherent weakness of the sealant chemicals, other parameters also influence sealant spray performance. These factors are discussed in the ensuing sections.

4.1.1 Spray Solution Volume and Concentration. The concentration of the chemicals applied to the coal surface will influence the performance of surface coatings. Although, the exact relationship between concentration and crust retention under operating conditions is unclear, for some dust suppressant products the crust formed by a higher concentration solution will be stronger than the crust produced by a lower concentration solution. However, evidence to support significantly improved overall crust retention as a result of applying a higher concentration chemical is limited. Other factors may have a greater influence on crust retention performance, i.e. more concentrated solutions may

not significantly increase crust retention performance unless accompanied by improved application techniques and improved load levelling.

There appears to be an optimum concentration range for most chemicals. Below this range the solution is too weak, while above the upper limit the effectiveness does not increase in relation to increased concentration. For certain chemicals too high a concentration can yield shallow penetration and thinner crusts than achieved within the optimum range.

In 1982, the two of the larger coal mining companies in southeast British Columbia supplied Environment Canada with details on both the concentration and quantity of sealant solution applied to each of their trains. These records confirmed that both the quantity and the concentration of the spray solutions applied at each mine could vary widely from month to month and often from train to train. Variation in solution concentration could account for some of the spray system performance inconsistencies observed at the Agassiz monitoring station.

Field observations (12) indicate that the spray facilities at each mine are different and some do not appear capable of providing adequate solution mixing or uniform application rates to each car. To ensure that an equal quantity of uniformly mixed solution or emulsion at the desired concentration is applied to each car in every unit train, a mine load-out spray installation should have a well designed mixing tank or in-line mixing unit. The accompanying flow-metering system should be capable of delivering equal volumes of sealant solution to each car (12).

Varying train speed through a mine load-out, spray facility has also been observed to cause the unequal application of sealant chemicals to cars within the same train. The train speed during loading can vary and stops can occur due to equipment failure either at the load-out or on the train. If a spray facility is not capable of adjusting solution flow rate to account for these changes, certain cars will receive unnecessarily high volumes of chemicals while others will not receive enough. It is recommended that mine operators who have these flow rate problems correct spray system design in order to ensure that uniform solution volumes of adequate concentration are applied to each car regardless of train speed. Some companies have overcome these problems and are achieving more consistent performance.

4.1.2 Application Techniques. There is no standard application technique for chemical sealants. Although the basic principle of mixing a commercial strength chemical with water and spraying the resulting solution or emulsion on a loaded coal car is

adhered to at all mines, the number of spray headers, the number of nozzles, their location, and the height of the headers will vary. Some mines use only a single spray header while others employ a series of consecutive spray headers (up to 5 at one site). Although the number of spray headers and the number of nozzles per bar may not be critical, a system designed to provide a thorough, even distribution of the spray fluid over the entire coal surface in a loaded car is essential.

Incomplete spray coverage of both the end slopes and the edges of loaded cars has been observed and is a factor in crust break-up and poor crust retention performance (8), (12), (24). Coal shippers, especially those experiencing performance inconsistencies, should inspect their spray facilities and ensure that chemicals are being applied in the most effective manner. Improved spray applicator design may be required.

Certain spray facilities employ multiple headers which spray cars alternately with chemical sprays and water-only sprays as the cars proceed through a spray installation. One reason for using the water-only spray is based on a theory that a water spray applied after a coating of a dust suppressant chemical will drive or carry the sealant forming chemical deeper into the coal surface thereby providing a thicker crust.

The effectiveness of post-sealant, water-only sprays in improving crust retention performance has yet to be demonstrated. Laboratory tests revealed that the addition of extra water to a coal surface previously sprayed with a latex-water emulsion did indeed provide deeper penetration, but it also increased run-off and increased the curing time of the crust. However, even though water soaking increased the curing time, the increased depth of penetration of sealant fluids provided a moist layer under the crust which appeared more resilient and more effective in limiting particle shifting, a major factor in undermining crusts on sloped surfaces (10).

Field observations of the effect on crust retention performance of water-only sprays applied after a latex emulsion were inconclusive (12). The net effect appeared to be either negligible or detrimental. Additional research would be required to determine whether flood water sprays, applied either before or after an application of chemical sealant, could improve crust performance.

Oscillating spray bars to increase surface coverage and preferential spraying, the application of more solution to end slopes, were tried and abandoned (3). However, because of the continuing problem of end-slope crust retention, the authors of a field study recommended that the effectiveness of preferential spraying be rexamined, especially as a method of improving coverage on end slopes which are particularly prone to crust failure (12).

Wind gusts during spray application at certain mines have been observed to distort spray patterns and to deflect sprays away from coal surfaces. This distortion in the spray pattern can result in incomplete surface coverage. Where this is a problem, increasing the spray pressure or reducing the height of the spray headers above the cars would alleviate wind distortion. Wind breaks or enclosures ensure more positive protection (10).

Cold weather can cause freeze-up problems with spray system piping and nozzles. In 1984 two mines in southeast B.C. reported spray system freeze-up as the reason for unsprayed cars or completely unsprayed trains. However, since only two mines experienced this problem in 1984, adequate freeze protection is obviously possible. The coal mining companies concerned should upgrade their freeze-up protection systems. Exposed lines and nozzles should be protected to prevent the freezing of fluids during the worst cold weather periods. Purging lines after use will also reduce freeze-up problems.

4.1.3 Curing Time. The curing time for surface coatings is the time required for a sprayed solution to set or to reach a stable or best condition for sealing a coal surface. The laboratory evaluation of sealant crusts produced by certain latex chemicals (10) revealed that fully cured crusts are stronger and less prone to fracture by vibration than partially cured crusts. However, at a mine load-out there may not be the time available per train to allow a crust to fully cure.

A 100 car coal train is normally loaded in 3 1/2 to 4 hours. Therefore, prior to the start of a journey, the crust on a car will have had a different curing time, compared to other cars, in relation to each car's position in a train. The cars at the front of the train will have crusts that have cured for approximately 4 hours while cars at the rear will have crusts that have cured for only a few minutes. Field observations have shown that the initial jolt or high amplitude shock at the start up of a 100 car train is sufficient to fracture the partially cured crust on a car at the rear of a train (24). However, the results of another study (12) failed to confirm that there was any significant increase in crust retention between crusts on cars at the front of a train and those crusts on rear cars. Recent tests involving different chemicals indicate that a fast curing time for chemicals other than latex may not be desirable.

For a chemical which requires a long curing time, it is impractical, for economic reasons, to increase the loading time of a train by several hours in order to allow crusts to fully cure. Suggestions for decreasing the curing time of a surface treatment chemical include: the application of heat to the surface of each car, the use of heated spray solutions, and the development of faster curing formulations (10).

4.1.4 Vibrations, Shock, and Load Settling. Vibration and shock, during train movement also appear to affect crust integrity. While a train is in motion the coal load, and hence any sealant coating, will be subjected to almost continuous low-level vibration and irregular high amplitude shock. Vibrations, which result primarily from wheel-rail interaction, vary in amplitude and frequency depending upon train speed and terrain. Shocks, which occur during starting, stopping, shunting and during high speed turns are usually of greater magnitude than the vibrations but occur less frequently.

During laboratory tests, it was shown that well-cured crusts could resist low-level vibration (less than 0.25 g) for over 20 hours without crust failure; however, a crust that had withstood ten hours of testing at low-level vibration with no damage could be destroyed in minutes by a slight increase in the amplitude of the vibration (10).

It would appear that even a well-cured crust may not be able to withstand the violent shocks of a rough train journey, and once a crust has been broken low-level vibrations will contribute to crust undermining and the further destruction of the surface coating. Constant low-level vibration will shift coal from under a crust thereby undermining a partially covered surface (particularly on partially covered end-slopes) causing further crust break-up and collapse (10). A flat, completely coated surface will be least prone to shock breakage and vibration undermining.

Low-level vibration can also sift fine particles upward through cracks or gaps in a surface coating where they may become wind entrained. Depending upon particle size, vibration also appears to lower the threshold dusting velocity for particle entrainment. This phenomenon was demonstrated during laboratory wind tunnel experiments (13).

Constant vibration will also result in the physical settling of a coal load. During an 1100 km trip from southeast B.C. to Vancouver the center portion of most coal car loads in a train have been observed to settle up to 30 cm (12), (24).

If a load settles uniformly, a well-cured crust appears to remain intact on flat surfaces but can break-up on distorted profiles or steep end slopes. The effect of load settling on crust break-up also appears to be severe along the side walls of cars at the coal-steel interface. A well applied crust or surface coating which is in contact with the car side or sill will break away from the car as the load settles.

At the end terminal, uncovered or exposed strips along the sides of most cars have been observed and photographed (12), (22), (24). These strips usually extend the entire length of the car along the central flat profile and vary in width from a few

centimeters to almost 30 cm. These uncovered side strips may not result entirely from load settling, but rather from a combination of settling, improper spray application, and load leveller aberrations created near the car sides.

At the end terminal the coal load along these strips has also been observed to be up to 20 cm below the coal load in the central, crust covered, portion of the car. The side troughs may also result from a combination of effects including: load settling, trenching by load levelling equipment, and wind erosion of exposed coal.

It is unlikely that load settling can be reduced, however, the effect on crust break-up can be reduced if slopes and profile distortions are minimized and if sprays are applied over the total load surface. The prime objective is to ensure a flat profile across the full length and width of each car.

4.2 Suggested Improvements to Spray Systems

4.2.1 Equipment Maintenance and Adjustment. Observation of loading and spraying operations at several of the western Canada coal mines (12), (24) has indicated that at certain mines the spray systems frequently fail to cover the entire coal surface in loaded cars with sealant chemicals. Although some performance failures may be traced to poor spray equipment design, spray coverage problems often result from temporary spray system faults due to inadequate maintenance.

Only one of the four spray facilities checked during a field evaluation was observed to achieve a high level of nozzle and spray pattern success on all of the trains checked (12). Plugged nozzles and improperly aimed nozzles were the reasons for the poor spray coverage of the trains loaded and for the chemicals wasted. Diligently enforced maintenance schedules for spray facilities are therefore essential to ensure proper system operation. Spray nozzle and header operation should be monitored during each train spraying and malfunctions corrected before the next train is sprayed. Spray patterns should also be tested and verified as the first car in a train is loaded and sprayed.

Accurate timing of spray activation and shutoff is also essential for complete spray coverage. The "on-off" operation of sprays is usually preferred in order to economize on spray solution that would be wasted on the ground between cars and to prevent possible fouling of coal car couplings and hydraulic equipment. However, timing errors can occur due to the failure of automatic spray control equipment or because of operator error in manual systems. Timing errors will result in partially coated end-slopes.

For those mining companies having problems, more thorough maintenance schedules for their chemical spray and load levelling apparatus should be implemented.

They should ensure that their systems are capable of total spray coverage of all end-slope areas and other exposed coal surfaces.

4.2.2 Car Respraying Systems. Nozzle plugging, spray bar freeze-up, automatic spray activation problems or operator error can result in a number of cars in a train receiving only a partial coating of sealant. In some instances, a loaded coal car has been observed to leave a mine without having been sprayed with chemical sealants.

At least three coal mines, one in southeast B.C. and two in western Alberta, have acknowledged the need to respray cars missed or improperly sprayed cars by instituting procedures to overcome this problem. At these three mines when problems are detected a train is backed through the spray system so that each car missed or only partially covered during the first run receives a full application of sealant chemicals the second time through.

If time constraints do not allow a long delay while a spray system is repaired or for a train to be backed through the spray headers, the installation of a secondary spray or respray facility at a mine site should be considered. This secondary spray system would provide a means of spraying cars missed by the primary spray without introducing costly delays.

Cars missed or only partially sprayed by the primary spray header, the first set of headers, could be treated with sealant chemicals by the secondary spray unit. In the event of total failure of the first unit, the secondary spray unit, equipped with a duplicate pumping unit, piping and spray header, would also serve as a complete standby system.

To operate the system, an observer or operator would be required to check each sprayed car, to identify the cars requiring a respray, and to activate the secondary unit. All cars identified by the operator as unacceptable would be resprayed using the secondary spray unit. The secondary spray unit could also provide a means of preferentially spraying or double coating distorted profiles and steep end-slopes. Where systems already employ several spray headers the installation of a secondary spray system would involve little additional hardware.

The following requirements are essential for the proper operation of a secondary spray unit:

- the primary and secondary units should be physically separated and at sufficient distance from each other to allow an operator to spot poorly covered cars and activate the second spray;

- the secondary unit should be independent of the primary unit, i.e. separate pumps, valves, meters, piping and spray headers;
- the secondary spray unit should have access to a sufficient volume of mixed solution to coat an entire unit train;
- the secondary spray unit must be subject to the same strict design requirements and maintenance scheduling as the primary spray unit.

Another suggestion is to employ a mobile spray system to coat cars missed by the fixed spray system. The problems with this approach are that in the event of a total breakdown of the fixed spray there may not be sufficient time or sufficient chemical for a mobile unit to spray an entire train.

4.3 Load Levelling Systems

The surface profile (the loading profile) of the coal in loaded cars is considered to be one of the most important factors in achieving good crust retention with sealant chemicals. A flat profile will present the best geometry for sealant crust retention and will create less unwanted air turbulence. Observations in the field and in the laboratory (2), (10), (12) confirm that most chemicals perform better when applied to level surfaces, therefore a flat surface on a coal load is an essential requirement for a high degree of crust retention. A flat surface will also limit sealant run-off and crust undermining.

Cognizant of this requirement most of the coal mines in western Canada have installed profile-levelling devices. However, the design of, the levelling systems and the effectiveness of levelling achieved differ from mine to mine. Certain companies rely strictly on a wide flood-loading chute to level a load (Figure 2), while others have installed separate levelling devices. The load leveller designs which have been tried or which are in use include: hard rubber flaps or skirts on loading chutes; hard rubber flaps on loading shed outlet doors; levelling bars; plow-type levellers; levelling rollers and compactor - leveller devices. Most of the devices are attached to or immediately follow the loading chute, although at some mines levelling devices are positioned at a location separate from the load-out.

Experience to date indicates that a completely level coal surface in a loaded car may be close to impossible to achieve given the current constraints of large coal train operations. However, observation of the load levelling facilities at certain mines has shown that some of these systems perform more effectively than others. Of the trains from the four mines observed during the system evaluation study, the two mines which

loaded their trains with the flattest loading profiles also achieved the highest overall crust retention averages (12).

The degree of success achieved with a levelling device depends not only upon leveller design but upon the type of coal car loaded, the characteristics of the coal on the day loaded, and the skill of the loading operator. The timing of coal release and shut-off is also crucial because it will determine the length as well as the angle of the end slopes.

One design of load leveller was observed to produce almost ideal profiles. These profiles had short, small-angle front slopes, long flat centre profiles and short, small-angle rear slopes with little or no coal left on the car sills. These almost flat profiles were achieved in part because of the near perfect timing of the release of coal into the front of the cars and the precise shut-off of coal near the end of each car. Load-out operator skill was also instrumental in the success achieved (12). Another advantage at this mine was that the train loaded comprised cars of almost uniform height containing coal loads at levels close to the top of the car sides. Coal car height can be a factor with respect to achieving flat profiles, (see Section 4.4).

Coal left on car sills has often been cited as a minor source of wind-blown dust. This problem is easily corrected by incorporating effective sill-sweeping devices as a necessary part of all load levellers. Where coal deposited on sills contributes to a fugitive dusting problem sill-sweeping devices should be employed.

Evidence collected since the original spray tests continues to confirm the theory that flat, well compacted, coal load surfaces are required for high crust retention efficiency and adequate dust abatement. Since there is no standard load leveller design, the companies shipping coal along rail routes where fugitive dusting is a problem should examine the installations which are achieving flat profiles and incorporate the best features. Side ridges, humped profiles, and steep end slopes should be significantly reduced or eliminated, otherwise the effectiveness of chemical sealants will continue to be jeopardized. Examples of car load profiles are presented in Figure 7.

4.4 Coal Car Height

The two most successful load levelling systems observed during a recent field study (12) were employed at mines loading coal cars of near uniform height. The height of a coal car and hence the height of the car sill above the rails will affect the positioning (or repositioning) of loading chutes and levelling devices.

Car height differences, especially if they occur from car to car within the same train set, require a loading operator (or an automated loading system) to adjust the

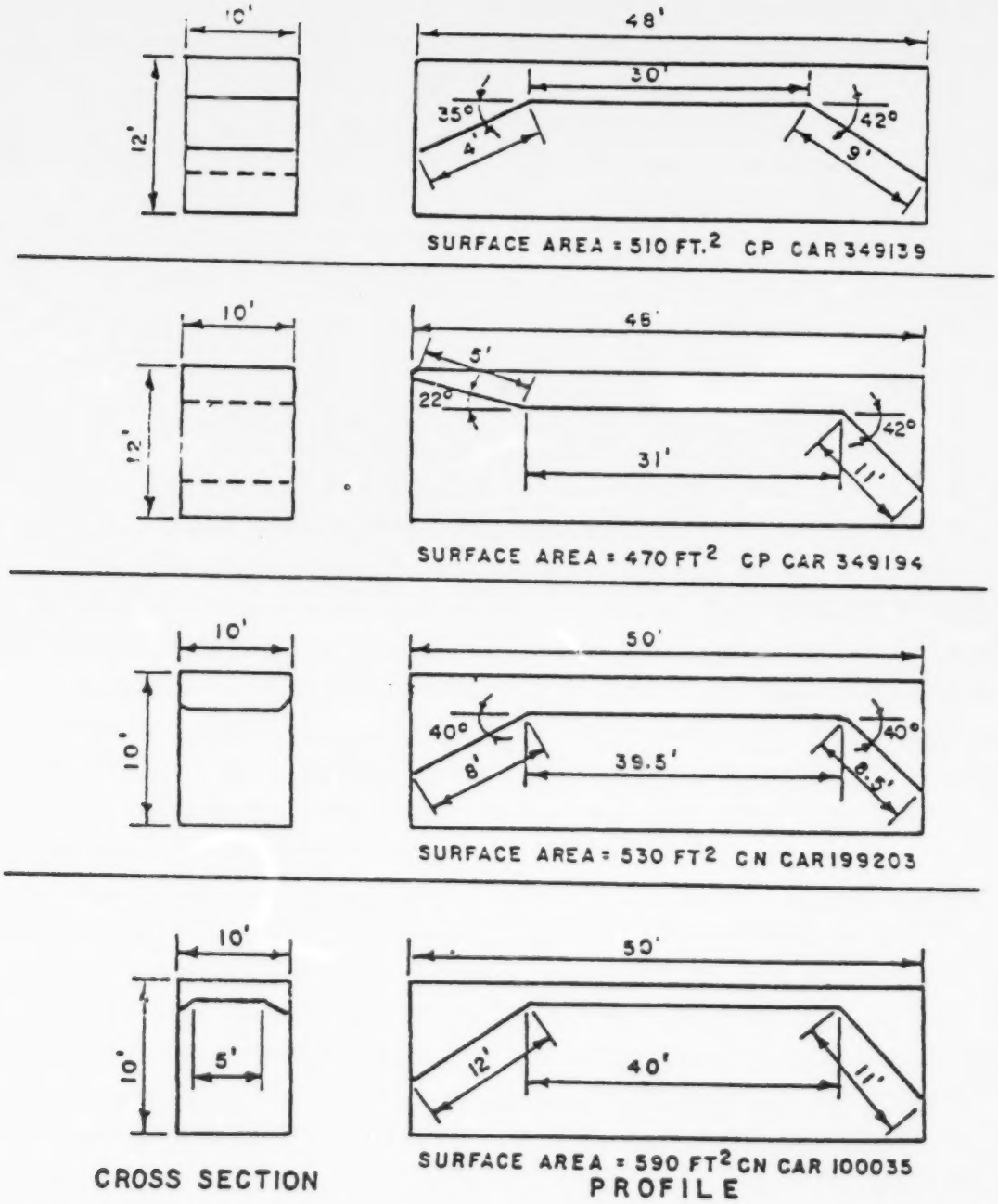


FIGURE 7 EXAMPLES OF LOAD PROFILES

position of the loading chute (and the leveller height) for each successive car. The delays and errors accompanying these adjustments frequently increase the length and angle of the end slopes of the coal load and have been observed to lead to humped or distorted profiles. Load leveller design is simplified if the train set to be loaded comprises cars of approximately equal sill height.

The maximum weight capacity allowed by the railway companies for loaded coal cars is 119 275 kg (263 000 lbs, car plus coal load), therefore, the height of the coal load in a car will vary with the height and tare weight of each car. The height of the coal load in relation to the sill height of the car, either above, even with, or below, will influence load leveller design and operation.

Many of the gondola-style coal cars now in service will exceed the maximum weight limit before they reach their volume limit. The result is that the top of the coal load is well below the top sills of the car (Figure 7). To level this type of load, a load levelling device must clear the front wall of the moving car and drop down to reach the coal load. The time lost in such manoeuvres will increase the length and angle of the end slopes. Delays in lowering and raising loading chutes can also result in distorted profiles.

Most of the trains loaded by the mines in northwest Alberta comprise cars of almost uniform height above the rails (coincidently the coal load height is almost even with the top sills). Observations (12), (22) show that these trains have consistently flatter load profiles than the trains loaded at the mines in southeast British Columbia. However, unlike the Alberta trains, most of the trains loaded in southern British Columbia comprise cars with sill heights which can vary up to 0.6 m from car to car within the same train set (24).

It is likely that cars of unequal height and capacity will continue in coal train service, therefore load levelling devices should be designed to overcome this inherent disadvantage. However, the railway companies could aid the mining companies by assigning cars of similar heights to specific train sets or by grouping cars of similar height and design within the same train set.

A suggestion to install false bottoms in high-sided cars so they may be loaded to the top of the car sides is considered impractical.

4.5 Operator Training and Automatic Systems

Some load levelling and spray systems at the mine load-outs are manually operated. Observation of manual operations has shown that profile distortions and spray coverage irregularities can result from operators misjudging car heights and coal slope

lengths in approaching cars. In some cases a spray operator's job is complicated by profile distortions caused by the loading operators (10), (24).

A change of load-out personnel during train loading (a shift change) at one mine was observed to result in a number of cars with load-profile distortions occuring before new operators became familiar with the loading rate of the falling coal (24).

The experience and skill of the personnel operating manually controlled loaders and levellers can be a determining factor with respect to the frequency of severe load profile distortions occuring in a given train.

Malfunctioning automated load-out equipment can also result in loading or spray system performance problems.

One mine reports that its load-out operators receive three years of training in loading operations, this could be a factor in the success with operating their spray equipment. Training programs should be provided for all load-out operators in the proper operating procedures for chemical spray systems and load levelling devices. Operators and maintenance personnel should be well informed as to the importance of correct equipment operation to successful crust retention performance and high dust control efficiency.

4.6 Overload Reduction - "Gouging"

The railway companies moving coal by train to Vancouver verify load weight by scaling cars en route. Before the installation of more sophisticated car weighing systems at the mine sites, overweight cars were flagged, and the the coal producers arranged for the excess weight to be removed by gouging the extra coal from the centre of a car using a front-end loader or similar device. Unfortunately when coal was removed en route the sealant crust protecting that section of the coal load was also removed. The uncovered coal was a source of wind-blown dust. From an environmental control perspective, this practice was and is unacceptable. The railway companies report that en route weight adjustment is no longer practiced, however if it should be necessary, environmentally acceptable methods of handling the over-weight cars are required.

Certain companies also adjust overloaded cars by "gouging" at the mine site. If gouging is necessary, then to reduce the risk of en route dusting the disturbed coal surfaces should be relevelled before spraying (or respraying). Several companies have indicated that relevelling after gouging is already the practice at their mines.

4.7 Unloading Systems - The "Empty" Car Dusting Problems

Empty rail cars returning from Vancouver coal terminals to the coal mines

occasionally cause nuisance dusting en route. In the Agassiz area, although significantly fewer dusting incidents are recorded for empty trains than for full trains, some empty trains are judged to be "heavily" dusting, Tables 1 and 10. Dust emissions from empty trains can result from coal which remains on exterior car surfaces or from frozen or dry coal left inside a car after dumping.

One coal terminal in Vancouver and the Ridley Island Terminal, Prince Rupert have installed washing systems to clean the exterior car surfaces. Exterior car cleaning is the suggested minimum requirement for "empty" coal car dust control for all terminal operations. If the cleaning system is a car wash it must be adequately freeze protected and incorporate wash water collection systems and a system for the treatment of any effluent discharges. Freeze-up of the car wash at one Vancouver terminal resulted in several "heavily" dusting empty trains and in subsequent dusting complaints in both 1984 and 1985. The freeze protection for this system should be improved.

Air jet car cleaning systems should employ dust collection systems to control fugitive dusting associated with the cleaning operation.

However, although an exterior car cleaning can remove loose coal from the outside of a car it can not remove the coal left in car bottoms after dumping. All of the coal terminals in western Canada plus the Thunder Bay Ontario terminal employ rotary dumpers to unload their trains. Even though cars are inverted when dumped, some coal may remain in the bottom. In winter this problem is accentuated by coal freezing to the sides and bottoms of the cars, increasing the quantity of coal not dumped. The amount of coal, water and ice remaining in dumped cars varies from less than a tonne during the summer to reported highs of 25 tonnes during the winter (10). Based on measurements during November and December 1975, "CN has reported an average of 3 to 6 tons of (frozen) coal returned per car" to the Vancouver area (21). Frozen water and coal carried as dead-weight represents an economic penalty because it reduces the coal load carried and if thawing occurs en route it may act as a source of wind-blown dust.

Several of the coal mining companies in British Columbia carried out a study during 1982/83 at the Roberts Bank Terminal in Vancouver to assess the effectiveness of chemical side-release agents. The work involved cleaning the interior walls of a number of test cars and applying a side-release chemical to the inside of the cars. The results of the study were inconclusive due in part to an unusual spell of warm weather in southern British Columbia, but regardless of the success of these agents, the cost of the treatment, estimated at $30 per car, was too high for general application to all coal cars unloaded during winter months.

Thaw sheds appear to be effective in achieving more complete car dumping during winter months at both the Thunder Bay and Ridley Island coal terminals. However, in southern B.C. thaw sheds have not been installed at the Vancouver terminals because thaw sheds are reportedly not cost effective in the prevailing moderate coastal climate.

A third method suggested as a means of removing coal retained on the inside of coal cars after they have been dumped is to wash the interior of the cars while they are inverted in the dumper. The disadvantages of this technique include extra moisture added to the coal during unloading, winter freeze-up problems, the time delay to spray, the water handling difficulties plus the cost of retrofitting the dumpers with high pressure wash nozzles. The industry considers the problems of water-coal separation and handling associated with this technique insurmountable for the retrofit situation. The use of air jets rather than water jets has potential, and would eliminate the problems associated with water jets. A feasibility study would be required.

Another solution to the empty-car dusting problem is car covers. A cover system should eliminate wind-blown dust emissions from coal carried on the inside of empty cars. Cover systems are discussed in detail in Section 5.2.6.

At present the only practical solution to fugitive dusting from coal on the inside of empty cars appears to be to reduce train speed through the communities where fugitive dusting is a problem.

5 DUST CONTROL OPTIONS AND MITIGATION MEASURES

Many ideas have been suggested as ways of improving the effectiveness of sealant spray systems, while others have been forwarded as new or alternative dust control techniques. In addition to technology options several mitigation measures have been suggested which represent changes to operating procedures which would serve as means of reducing or dealing with the environmental impact of coal dust pollution from coal trains. A number of these dust control options and mitigation measures are listed in Table 11 (3), (32). In the discussion which follows the various mitigation measures and control options are grouped according to the coal industrial sector that would most likely be directly responsible for their implementation, i.e., the railway companies, the coal mining companies or the coal terminal operators. The advantages and disadvantages of each technology option are listed in Appendix A.

As noted on Table 11, many of the options are neither technically nor economically practical, however for those less familiar with the subject a brief explanation of each option has been provided.

5.1 Mitigation Measures and Options - Railway Companies

5.1.1 Reduce Train Speed. In 1981, a speed restriction was implemented voluntarily by the CPR for dusting trains through Agassiz, B.C. This speed restriction is only a temporary administrative order to train crews, and not a legal requirement. Whenever a train approaching the town is assessed as "heavily" dusting by the train crew, the train crew has been requested to reduce speed. During conditions of little or no ambient wind, a significant decrease in visible dusting is observed if coal train speeds are held below 50 km/h (30 mph).

This operational procedure has been observed to be effective in reducing visible dust emissions, but is not strictly enforced. Of 61 medium and heavy dusting trains sighted in Agassiz in 1984, 19 were at speeds greater than 50 km/h.

One drawback to the technique is that if a train crew cannot easily determine whether their load is dusting "heavily" (e.g., during non-daylight hours), the train will usually maintain its rated track speed (80 km/hr).

Another problem with speed reduction as a method of dust control is that during periods of dry weather and high ambient wind, dusting can still occur even from a slowly moving train. Observations at Agassiz, B.C. have confirmed this phenomenon (4).

TABLE 11 COAL DUST MITIGATION MEASURES

	Technique		Status
A)	**Options - Railway Companies**		
1.	Reduce Train Speed	-	In use for one community
2.	Uniform Design or Grouped Coal Cars	-	Too many mismatched cars for either a replacement or a re-trofit program - car grouping suggested
3.	Ban Above Car Loading	-	Effectiveness unproven - Few cars in service
4.	Aerodynamic Modifications to Cars	-	Suggested - Design required - Feasibility questioned
5.	Switch to an Alternative Transportation Mode	-	Presently impractical
6.	Cease Operations	-	Unacceptable
7.	Reroute Trains	-	Not attempted - Impractical
8.	Buy Property or Homes	-	Beyond the scope of this report
9.	Damage Compensation Payments-Yearly Stipend	-	Beyond the scope of this report
B)	**Dust Control Technology Options - Coal Mining Companies**		
1.	Flat Load-Profile and Load Compaction	-	Acceptable levelling systems are in use but improved systems are required at some mines
2.	Improved Chemical Sealant Application Techniques	-	Some acceptable systems are in use. Experiments required for new techniques. Secondary sprays are recommended at some mines
3.	New Chemical Sealants	-	Chemical Sprays are Used by All Major Coal Shippers - New chemical testing continues
4.	Increase Chemical Sealant Concentrations	-	Testing ongoing at some mines
5.	Chemical Sprays - En Route	-	Suggested for Test - Practicality questioned
6.	Hinged Covers	-	One system operating in U.S.A. Redesign would be required for Western Canada - Presently considered impractical

TABLE 11 COAL DUST MITIGATION MEASURES (CONT'D)

Technique	Status
7. Lift-off Covers	- Design available - Prototype testing required - Presently considered impractical
8. Roll-Back Covers	- No prototype available - Presently considered impractical
9. Soft Once-Only Covers	- No prototype available - Presently considered impractical
10. Briquettes	- Suggested - Practicality unknown
11. Water Spray En Route	- Not in Use - Practical for limited application
12. Coarse Coal Topping	- Attempted and abandoned
13. Water Spray at Mine Load-out	- Short distance only - Used on some coal trucks
14. Remove Coal Fines	- Not in use - Impractical
C) Control Options - Coal Terminal Operators	
1. Interior/Exterior Car Cleaning	- Exterior Car Washes at Two Terminals - No Interior Car Cleaning
2. Thaw Sheds or Side Release Agents	- Thaw Sheds are In Use at Two Terminals; Side Release Chemicals are Under Test

However, economic penalties represent a more serious drawback to the general implementation of this technique. Although dust emissions are less at lower train speeds, the Canadian Transport Commission and the railway companies are reluctant to impose or agree to mandatory speed reductions. A mandatory speed reduction in one town would not jeopardize existing train schedules; however a general requirement to reduce speed in all communities en route would increase the round trip times and would seriously effect the movement of coal. There are over 30 small towns along the rail route from the coal fields in the southeast of British Columbia to Vancouver, a requirement to reduce speed in all of these communities would result in a need for more trains and more train

crews to maintain the same annual volume of coal shipped. This is unacceptable since it would increase the cost of export coal and place an additional burden on the existing rail network. The rail system is already severely taxed to handle the present coal traffic.

Therefore, train speed reduction as a dust control option is only effective if strictly enforced and used in conjunction with other abatement techniques. It is only economically viable as a dust mitigation measure for very specific locations and circumstances. If only a few "heavily" dusting trains occur, along a rail corridor, the railway companies involved should consider implementing a speed reduction for such trains in order to reduce adverse nuisance dust impacts on communities. At present, speed reduction appears to be the only practical and immediate solution for limiting dust emissions from coal retained on the inside of empty cars transitting Agassiz, B.C.

5.1.2 Uniform Design or Grouped Coal Cars. A sizeable fleet of cars with significantly different dimensions is currently in coal train service. The result of a non-standardized coal car fleet is that a mixture of cars of different sill heights can occur within the same train set. Car height differences within the same train set can lead to non-flat coal profiles which can result in crust retention problems and reduced performance effectiveness for spray dust-control systems.

A uniform design for all coal cars would solve some of these loading problems, but because of the large number of mismatched cars in coal train service, a car replacement or car retrofit program would be expensive and impractical.

For the southeast B.C. to Vancouver rail corridor, one suggestion for improving the existing situation is to organize train sets so that cars of a similar kind are grouped together either as whole train sets or as groups of like cars within the same train set. Implementation of this practice by the railway company involved could introduce some problems, but it will facilitate loading and thereby contribute to more consistent, flatter load profiles in the loaded cars. It was thought that the new marshalling yard under construction by the CPR at Golden, B.C. would assist that railway in achieving the grouping of uniform height cars for the southeast B.C. coal producers, but scheduling difficulties could preclude any such grouping.

5.1.3 Ban Above Car Loading. There are some low bulk-capacity cars in coal train service. The number of such cars has been reduced substantially in the last decade. These cars are loaded to a level above the sills in order to achieve the maximum allowable weight limit. Coal cars loaded in this manner expose the above-car coal surface to excessive wind erosion which leads to rapid crust-cover degradation and possible dusting

en route. To avoid over-height loading, it should be feasible to restrict load heights so that the top of the coal load is level with the top of the car sills.

However, since there are few such cars now in service the seriousness of this problem and the need for a loading restriction have been questioned by the industry. A height restriction could reduce coal loads and the resultant economic penalty would result in increased transportation costs. However, an announcement by the CPR that they are introducing a new car with an even lower side sill than their existing rolling stock may have repercussions in this area.

One suggestion for resolving the volume-limit load problem is to extend the wall height of small bulk-capacity cars by adding side wall and end wall extensions; these extensions would bring each car up to its rated weight capacity. These car modifications are considered unacceptable because of the possibility of interference with loading and unloading apparatus and the cost of retrofitting the cars.

5.1.4 Aerodynamic Modifications to Cars. Experts in low speed aerodynamics have suggested that several longitudinal or lateral crossmembers fixed to the top of a coal car would reduce air turbulence and thereby reduce dust entrainment of surface coal particles. Studies would be required to develop optimum design configurations and to determine whether the reduction in fugitive dusting resulting from the installation of such devices would warrant the problems associated with interference in the loading and unloading operations plus the expense and logistic difficulties of retrofitting the large fleet of coal cars. The feasibility of adding any structure which would span the top of a coal car has been questioned.

5.1.5 Switch to an Alternative Transportation Mode. Switching from trains to another mode of transport is presently impractical because there is no viable economic alternative to rail transport.

Truck transport, conveyors and coal slurry pipelines have been suggested as alternative methods of large volume coal transport, however there are many legal, economic and technical difficulties associated with the transport of large quantities of coal over long distances by these methods. A discussion of these difficulties is beyond the scope of this report.

5.1.6 Cease Operations. Closing down a coal/rail network is not a realistic option.

5.1.7 Reroute Trains. The possibility of rerouting coal trains around communities has been suggested as a method of reducing population exposure to wind-blown coal dust. Although technically feasible such action is also not a realistic option.

5.1.8 Buy Property or Homes. The suggestion to purchase homes or properties that suffer nuisance dust impact from heavily dusting trains would seem unrealistic in view of the large number of homes and businesses exposed to nuisance dust pollution. The legal ramifications of this approach are beyond the scope of this report.

5.1.9 Damage Compensation Payments - Yearly Stipend. The social, political and legal ramifications of paying citizens subjected to nuisance dust pollution a yearly stipend to compensate for property damage are also beyond the scope of this report.

5.2 Dust Control Technology Options-Coal Mining Companies

5.2.1 Flat Load-Profile and Load Compaction. Coal cars should be loaded with the coal profile as flat as possible. Evidence gathered during field studies and from laboratory tests continues to support the theory that chemical sprays will only be capable of adequate dust control if they are applied to virtually flat, well compacted load profiles. Crust breakup on non-flat coal profiles appears to be one of the prime reasons for en route crust failure. In addition to a flat profile, load compaction can further contribute to forming more stable crusts.

This requirement for a level load has been known for many years, and some systems are more successful than others in achieving acceptable load profiles for dust control when chemical sealants are applied. However no load-out facility in Canada is yet capable of achieving a completely flat load profile in a moving coal car. A discussion of the problems involved in coal car loading is contained in Section 4.3.

5.2.2 Improved Chemical Sealant Application Techniques. The application sequence for chemical spraying may influence crust retention. One sequence, employed at several coal mine load-outs, involves the application of chemical solution from one spray header followed by the application of a water soak from a second spray header. The purpose of the water soak is to increase the crust penetration of certain types of chemical sealants (10). The results of the field surveys investigating possible performance improvements from using this technique have been inconclusive (12) (Section 4.1.2).

Another sequence had one spray header coat the entire coal surface with sealant chemical while a second spray header applied a second coat only to steep end slopes. This technique, known as preferrential spraying, was tried and abandoned by at least one company. It has recently received renewed interest because of the continuing problem of poor crust retention on end slopes.

Most spray systems do not allow an operator to make corrections for poorly sprayed cars or for cars which do not receive any sealant chemical coating because of a system malfunction. Coal cars which do not receive an adequate coating of sealant chemicals can become sources of fugitive dusting en route unless they are resprayed. Respraying is accomplished at some mines by backing the sprayed train through the system to recoat missed cars. Other mines respray from a second spray bar. When train reversal through the spray system is not possible, a secondary spray facility has been suggested as a technique to ensure that all cars are properly coated with chemical sealants.

Many spray sequences and application techniques are possible. For maximum dust control a mine must optimize both its spray system design and application method.

5.2.3 New Chemical Sealants. It has been suggested that new sealant products or new chemical formulations could improve the crust retention performance of the existing sealant spray systems. Since the inception of coal car spraying, numerous chemical formulations from a variety of suppliers have been marketed as coal dust suppressants or for other applications such as road dust control, see Appendix B for a partial listing (31).

The most obvious advantage of a new and "better" chemical sealant is that little capital investment is required, the facilities for spraying the chemicals are in place at all of the major coal mine load-outs in western Canada and therefore the cost of implementation is low. The coal mining companies continue to experiment with new chemicals.

5.2.4 Increased Chemical Sealant Concentration. Increasing the concentration of certain commercial chemical sealants in the total fluid sprayed on each car could improve crust retention.

Laboratory experiments (10) have shown that for latex sprays, in general, higher concentration sprays provide stronger crusts. However, in the field, the observed overall performance improvements have been minor (12).

Since the interaction of many performance related parameters can mask the effect of increasing sealant concentration, a mine experiencing a dust control problem should test chemical sealants at various concentrations in order to establish the optimum concentrations for their chemical under given operating conditions.

5.2.5 Chemical Sprays-En Route. The installation of one or more secondary chemical sealant spray facilities en route has been suggested as a means of controlling dust emissions through sensitive areas and communities. An en route spray system (or

systems) could be installed at a location along the transportation corridor where the initial crust-cover provided by sealants sprayed at the mine load-out may have broken down and satisfactory coal dust control is no longer being achieved. This technique is potentially feasible, however, administrative difficulties and rail operating logistics could make implementation impractical. Testing is required. The associated capital and operating costs are substantial, but they could be shared by several companies.

5.2.6 Permanent Covers. The solution to the wind-blown dust problem suggested most frequently by lay persons is to cover the coal cars. Although the concept of a covered car appears simple, the application of this dust control technique to the existing coal/rail network is technically complex.

In 1981 Environment Canada commissioned an evaluation of the feasibility and cost of using car covers on coal trains in Western Canada (11). The findings of this feasibility study indicated that a permanent, automated car-cover system would provide more effective control of airborne coal dust emissions, and could alleviate the possible build-up of snow and rain in empty returning cars. However, the coal industry feels that at this time the potential cost of retrofitting this technology to the entire western Canada coal-rail network make covers impractical. (Cost estimates are discussed in section 6.) The industry has also questioned the wisdom of investigating covers when fugitive dusting is a reported problem only for specific communities on two of the seven major rail corridors illustrated in Figure 1.

The coal industry is also concerned about cover and cover handling-system reliability in continuous coal train service. As noted in Section 3.1, the unit train concept is predicated upon rapid loading, unloading and transport of coal from mine to coal terminal, the industry feels that the inevitable delays caused by jammed or otherwise inoperative covers or cover handling-systems could result in serious economic penalties.

The authors of the feasibility study (11) felt the only way to overcome all of the compatibility difficulties which could be encountered was to employ a lift-off or removable cover. However, a complex design, such as the lift-off system presented in Reference 11, was of particular concern to the coal industry. They felt that problems would be especially severe during winter months when ice and snow would cause serious operational problems with the cover batching and handling apparatus. The coal industry and federal transport officials have also stressed that a fail-safe cover clamp down system must be proven before automated cover systems would be acceptable.

There is one automated cover system in operation in the U.S.A. on coal train service (33). Although difficulties were experienced during the early years of operation of this system, as "bugs" were worked-out-of unproven equipment, company personnel claim the system has been virtually breakdown and maintenance-free for the last five years. Based on recent observation, this specific system of automated covers has shown to be effective technology.

However, the system in the U.S.A., which employs a steel, hinged-cover, is designed for a specific coal mine to power plant operation. The western Canada coal transportation network is complex and before automated cover systems can become a reality in Canada a major integrated program involving government and industry to design and build an acceptable prototype system will be required. The requirements for such a prototype test program were developed in a study contracted by Environment Canada (34).

Several different styles of permanent automated coal car covers have been suggested. Three types, removable, hinged and roll-back covers, are discussed below. The advantages and disadvantages of each type are listed in Appendix A.

Materials suggested for all three styles of permanent covers include: canvas, woven plastic, fibreglass, fibreglass-reinforced-plastic, rigid plastic, aluminum, steel, rubber and combinations of these materials. Because of the significant economic penalty associated with coal payload displacement due to cover weight, the materials used in the construction of the covers will be critical. Covers must not only be as light as practicable, but the cover material must be rugged enough to withstand extremes of ambient conditions, plus the very rough handling they will receive in coal train service. For these reasons "soft" cover materials such as canvas and woven plastic are felt to be impractial for continuous long-term use on coal trains. The merits of various cover materials are discussed in detail in Reference 11.

5.2.6.1 Hinged Covers. Hinged-cover designs include two piece covers hinged at the sides of the car which operate like a clam shell or multi-segment covers individually attached with hinges to one side of the car box. The existing hinged-lid system in the U.S.A. (discussed in section 5.2.6) employs a five section cover hinged to one side of the car (32).

The main advantages of hinged-lid cover-systems in contrast to removable lid systems are:

- complex cover handling systems are not required. The lid-lifting or opening mechanism at the mine load-out is a simple scroll which requires little maintenance.

Covers are designed to open by their own weight when inverted in a rotary dumper, therefore there are no additional equipment requirements at the unloading terminals;

- although redesign is required for the Canadian scenario, hinged cover technology exists and is being used in the field;
- hinged-lid systems are mechanically simpler with attendant better reliability.

The main drawbacks to hinged covers concern compatibility with existing facilities are:

- the car clamp mechanisms on the rotary dumpers in western Canada are different from the one employed on the system in the U.S.A. Cars are clamped on the upper sill in the Canadian rotary dumpers whereas the dumper in the U.S.A. clamps each car on the lower sill thereby allowing full lid freedom during dumping;
- the existing hinged-lid system would require a major redesign before it could operate in conjunction with the smaller end-rings of the rotary dumpers in use in Canada;
- the rotary dumpers at the west coast terminals do not all rotate in the same direction. These rotational differences combined with the railway's requirement for periodic car reversing to equalize wheel wear would necessitate complicated train switching arrangements in order to ensure that cars entered dumpers with the lids oriented in the correct direction. The rerouting and switching required could introduce delays and economic penalties;
- all of the load-out facilities in western Canada are different. Many of the existing load-outs would have to be rebuilt to accommodate lid-swing, to allow scroll access and to restore loading operator visibility; and
- the differences in rolling stock require that several different sized covers be manufactured in order to fit all of the coal cars now in service.

Compatibility problems will make it difficult to develop a universal hinged-cover design for retrofit into the existing coal/rail network.

5.2.6.2 Lift-off Covers. This style of automated cover system employs a single rigid-lid that is lifted off the coal car to allow unrestricted loading and unloading. Construction materials can be selected to optimize service requirements of ruggedness, reliability, minimum weight and safety. A conceptual design for a removable lift-off fibreglass cover system capable of retrofitting to the existing unit train service in Canada is is presented in reference 11.

The principal advantages of removable covers in comparison to hinged covers include:

- the coal cars (with the covers removed) may still be used in service to shippers who are not equipped with a cover handling system at their load-out facilities;
- a removable lid system can be retrofit to the existing coal train service without major changes to coal mine load-out systems and car dumpers (although some minor modifications to these facilities would be required).

The main disadvantages relative to hinged-lid systems include:

- the technology for automated removable-lids is not proven whereas hinged-lid system technology is in operation in the field;
- a complex cover handling system with its attendant reliability and maintenance problems is required at both the loading and unloading facilities in contrast to the relatively simple fittings which would be required for a hinged cover system.

Other lift-off designs which belong in this category are non-rigid linked-rubber mats (similar to blasting mats) and solid flexible rubber mats. These mat style covers would fit inside the top of loaded cars, would be held down by their own weight, and would be removed by hooks snagging attached eyelets. Practical designs have not been developed.

5.2.6.3 Roll-Back Covers. This style of lid is designed to roll back into either an end or a side housing during loading and unloading operations.

The advantage of this system would be that cover opening and closing apparatus required at both the loading and unloading facilities should be relatively simple and should also be compatible with existing facilities.

The disadvantages relate to the lack of proven technology and the requirement for a potentially complex lid system with serious reliability problems due to jamming especially during winter icing.

5.2.7 Soft Once-Only Covers. The Saran-wrap approach or once-only cover system differs from the lid systems described above in that although the covering system is automated the coal cars are not fitted with a permanent lid. Instead, after coal loading, cars are fitted with a soft cover that is discarded at the end terminal. These covers differ from existing soft covers used in the ore transportation industry in that they would be applied automatically in order to conform to the time constraints of coal train operations.

Soft once-only cover systems have several significant advantages when compared to permanent or fixed cover systems. These benefits include: the use of cars by shippers who do not have cover application equipment at their coal load-outs, lower additional weight per car, and less safety hazard in the event that covers are accidentally released in transit.

However, the once-only cover concept suffers because of a lack of proven technology for automation and the potential for frequent cover damage and hence uncovered coal surfaces. Unless there is a breakthrough in the state-of-the-art for cover material, it is unlikely that a soft cover system will be practical.

5.2.8 Briquettes. Preparing coal for shipment in the form of briquettes, such as the familiar charcoal briquettes, would serve to agglomerate the coal fines and retain them within the coal cars. This is a novel approach with respect to large capacity coal production and has not been researched from this perspective. Although briquettes could reduce fugitive dust generation during all stages of product coal handling, the capital cost of the briquetting facilities could be prohibitive when applied to large scale coal production. Compatibility with end product use, especially in the metallurgical coal industry, would also require investigation.

5.2.9 Water Spray-En Route. Water sprays along rail transport routes have been proposed to augment the existing sealant spray systems. The flood-water spray-systems would be located in advance of the communities where heavily dusting loaded coal trains have caused problems.

An en route, flood-water spray facility would be simpler than a chemical spray system because the spray bars could be built high enough above the track to allow free movement of all trains and no mixing apparatus would be required.

However, during dry weather a water spray may only solve the dusting problems of a single community. If spray systems were required before several communities en route, the installation and operating costs for a large number of systems could be prohibitive.

5.2.10 Coarse Coal Topping. One coal mining company attempted to limit fugitive dusting by adding a layer of coarse coal over the top of each coal load, however the company eventually dropped the practice in favour of chemical sprays (3).

Both the feasibility and effectiveness of this approach are questionable. The main disadvantages are: load-out systems would have to be re-designed to handle, store and load coarse coal, there may be insufficient coarse coal in the product stream to

adequately cover every car, and a highly friable coarse coal will continue to breakdown and release fines even after separation.

5.2.11 Water Spray at Mine Load-Out. Because the surface agglomeration provided by a water-only spray would only last for a few kilometers (in hot, dry weather) water sprays would not be installed at mine sites as the primary dust control system unless transport distances were very short. This technique was employed by one coal mine to control dusting from trucks that carried coal on a public highway from the mine to the preparation plant.

Water sprays containing surface-active or wetting agents would increase the depth of fluid penetration, but the exposed surface would still be prone to rapid dry out.

5.2.12 Remove Coal Fines. The suggestion has been made that coal dust emissions could be reduced if coal fines were removed from the product coal stream at a mine and only the coarse coal fraction shipped by rail. The coal fines would be separated and used near the mine site.

Considering the large percentage of fines in western Canadian coal, a market for the coal fines in the vicinity of the coal mine would have to be found before the technique would be economically viable. Therefore this idea is considered impractical.

5.3 Control Options - Coal Terminal Operators

5.3.1 Interior/Exterior Car Cleaning. Coal dust blown from trains can also originate from coal deposited on sills and other exterior car surfaces during unloading operations. At present, coal is removed from exterior car surfaces at two of the three west coast coal terminals using an exterior car wash. Properly maintained exterior car cleaning systems (either air or water systems) are a minimum requirement for all coal terminals in order to remove this known source of fugitive coal dust emission. Water washing systems must have adequate freeze protection and incorporate water collection and treatment facilities. Air jet systems must incorporate dust collection systems.

An exterior cleaning does not however reduce fugitive dust emissions resulting from coal retained on the inside of unloaded cars. Coal inside cars is another source of so-called "empty" car dusting. Spraying water into returning cars has been suggested in order to reduce dusting from empty cars, however, adding water to empty cars would cause drainage and winter freeze-up problems. It is unlikely that an interior car wash could be employed with the cars in the upright position.

One suggestion for removing coal from the inside of coal cars is to design an interior car wash which directs clean-out sprays at the inside of coal cars inverted in a rotary dumper, the exterior surfaces of the cars are washed at the same time. The industry feels that the problems of water-coal separation and handling associated with car wash sprays within a rotary dumper are insurmountable for the retrofit situation. High pressure air jets to remove the undumped coal from inverted cars have been suggested as an alternative. This technique would eliminate the water handling problems.

5.3.2 Thaw Sheds or Side Release Agents. During winter months moisture in coal can cause coal to freeze to car bottoms and remain there even after dumping. This phenomenon, referred to as "frozen coal carry-back", can impose an economic penalty on coal shippers and if frozen coal in "empty" cars thaws en route it can also become a source of fine coal for wind-blown dust emissions.

Two methods for removing frozen coal from loaded cars are: to install and operate thaw sheds at the end terminals or to employ "side release" chemicals to prevent coal build-up. Thaw sheds work, but the terminal operators claim they are only economically viable in the colder regions of western Canada. For the warmer areas adding "side release" agents to the coal may solve frozen coal carry-back problems, but their cost effectiveness has not been fully assessed and further research is necessary.

6 COSTS - COAL DUST MITIGATION METHODS

The industry has not accepted the cost estimates presented in this report nor those presented in the two listed references (11), (18). However, for "reasons of confidentiality", the industry has also declined to provide input to this discussion of control system costs.

Because of the highly competitive nature of the world coal market any increases in operating costs can have serious ramifications to the Canadian coal industry. Therefore, capital and operating costs are major factors influencing the selection of dust-control systems. The only dust control technology in use on coal trains in Western Canada is to spray the coal with sealant chemicals at the mine load-out. A coal transportation network in the U.S.A. employs an automated cover system to control dust emissions and even though no such system has been installed in Canada, attempts have been made to estimate the cost of using car covers in western Canada. (11), (18). The discussion in this section centres on these two dust-control methods. An indication of the relative cost of other control technology options is presented in Appendix A.

The implementation of dust control technology entails both capital and operating costs, however it results in a reduction of coal losses and increased sales revenues. The cost effectiveness of the dust control measures will depend on the relative magnitude of the increased revenues due to coal loss reduction, compared to the costs incurred in installing and operating the dust control systems. Although chemical sealant systems have been operated in Canada since 1975, no reliable estimates of coal loss reduction during transport exist. Therefore, there is some uncertainty regarding the cost effectiveness of spray systems and studies designed to estimate the overall cost of such systems have assumed levels of coal loss reduction.

Similar uncertainty surrounds the estimated costs of operating automated rigid-cover systems in Canada. Although automated car-covers are proven technology (as demonstrated by the Gascoyne coal mine to Big Stone power plant system which has been in operation in the USA since 1975), there are major difficulties associated with retrofitting that cover system design to the western Canada coal transport network. Incompatibilities with respect to the mixed fleet of cars, the variety of load-out configurations and the style of rotary dumpers would increase the cost of developing, installing and maintaining a universal cover system. Certain assumptions have been made when performing engineering studies to estimate the cost of implementing cover systems. These assumptions are largely unsubstantiated and uncertainty surrounds the cost estimates obtained.

Two studies (11), (18) have attempted to estimate the cost, in Canada, of using chemical sprays and rigid cover systems for coal dust control. One of the studies (18) was performed for a group of coal producers, in 1980, by a team of consulting firms investigating the potential for coal dust contamination of wood pulp at the then proposed Ridley Island coal terminal and the other for Environment Canada in 1981 (11). Both studies involved comparisons of the cost of dust control using chemical sprays, steel covers and fibreglass covers when shipping coal a distance of 1100 Km. Unfortunately the cost estimates in both of these studies contained assumptions with respect to many unsubstantiated parameters which biased the final overall cost estimates in favour of the preferred dust control system. (See Appendix C for a discussion of these assumptions.)

The following analysis uses the same cost estimating technique as employed in References 11 and 18 but adjusts the assumptions to remove much of the bias. A more detailed discussion of these two studies is presented in Appendix C.

6.1 Chemical Spray Systems and Rigid Car-Covers

An attempt has been made to improve upon the previous cost estimates (using the same costing technique employed in the Ridley Island Study, Ref. 18) by updating the historic costs to present value for similar equipment and by eliminating obvious bias. Table 12 presents the anticipated costs of operating the conceptual spray and cover systems. Because of the uncertainty attached to many parameters and the number of assumptions required, high and low estimates have been provided for each control option. An indication is also given as to how much the assumed unit shipping cost ($19 per tonne) would be increased by implementation of the control measures. A description of how these costs were generated is presented in Appendix C.

Table 12 also indicates the relative contribution of the major cost components (materials, labour, maintenance, capital costs and displaced cargo charges) to the overall cost of operations. In general (except for the extra wheel-maintenance factor for steel-hinged covers), the impact of assumed labour and maintenance requirements on the overall costs is low.

The following points are noted for the specific systems:

(a) Chemical Spray Systems

The implementation of chemical spray systems results in two major costs, firstly the direct cost of the chemicals used and secondly an indirect freight penalty introduced as a result of the weight of the sprayed fluids displacing coal cargo.

TABLE 12 ANTICIPATED OPERATING COSTS OF THREE DUST ABATEMENT METHODS

Parameter	Chemical Sprays (1) Low	High	Fibreglass Lift-Off Covers (2) Low	High	Steel Hinged-Covers (3) Low	High
Total Estimated Operating Cost ($/Tonne Coal Shipped)*	0.16	0.34	0.57	1.18	0.88	1.31
Total Cost as a % of Present Shipping Costs -**	1% to	2%	3% to	6%	5% to	7%
Relative Influence of Cost Components (%)-						
Labour -	1	3	3	2	0	0
System Maintenance -	1	2	13	11	5	3
Extra Wheel Maintenance -	0	0	0	0	0	15
Chemicals -	64	60	0	0	0	0
Capital Recovery -	4	8	58	67	41	28
Displaced Cargo -	30	27	26	20	54	54
	100	100	100	100	100	100

* The derivation of these estimates is described in Appendix C.
** Assumes a shipping cost of $19 per tonne.

(1) For detailed $ cost estimates see Table C3.
(2) For detailed $ cost estimates see Table C5.
(3) For detailed $ cost estimates see Table C7.

The cost of control using sprays is very sensitive to the amount of chemical used. Spray materials account for approximately 60% of the estimated system costs. In comparison the labour, maintenance and capital charges are minimal, Table 12.

Varying a number of the spray system cost parameters has produced cost estimates in a range from $0.16 to $0.34 per tonne of coal shipped. The corresponding estimated increase in the shipping costs was 1 to 2 percent (Table 12).

Coal product loss en route due to fugitive dusting is not a true spray system cost, however, since spray systems do not provide 100% dust control (while cover systems do), the importance of this factor with respect to other spray system cost parameters has been tested. The effect on the overall system cost of adding a coal dusting loss factor (decreasing the dust control from 100% to 85%) was to increase the "high" cost estimate by approximately 30%. (Appendix C).

(b) Steel Hinged-Covers

Rigid, steel covers represent a capital intensive means of dust control. A fully developed and tested system would involve minimal direct operating charges, other than for cover maintenance. The capital charges to amortize the equipment over its estimated useful life are estimated as 28 to 41% of the total cost.

A major expense involved with the steel cover system occurs indirectly as a result of the heavy covers which reduce the coal carrying capacity of the cars. It has been estimated that this cargo displacement factor can be responsible for approximately half of the overall costs.

A second, sizeable indirect expense is the increased car maintenance which may be introduced due to the inability of the railroad companies to exercise normal car rotation procedures designed to balance uneven wheel wear. Investigators (18) felt that lids hinged to one side of a car could require the car to be hauled in the same direction at all times, the extra maintenance could represent up to 15% of total system costs.

The steel hinged-cover operating cost estimates range from $0.88 to $1.31 per tonne of coal shipped and may increase the shipping costs by 5 to 7 percent (Table 12). Note that the costs of rotary dumper modifications are not included since any cover design which requires a major rebuilding of the rotary dumpers is considered unacceptable.

(c) Rigid, Fibreglass, Lift-off Covers

Installation of fibreglass covers will result in a similar expense profile to that of the steel covers with the major cost being the amortization of the capital cost of the

covers, and their handling system, over their useful lives. Capital recovery is estimated as up to 67% of total system costs. The second largest cost is the indirect cost of reduced coal carrying capacity due to cover weight. The influence of this factor is very sensitive to the assumed weight of the covers. Cover weight penalties may account for up to 26% of the total system cost.

For the conceptual designs studied the fibreglass covers were lighter than the steel-lids, hence the magnitude of the freight penalty was lower. Also, a car rotation penalty for this cover system was not included since the style of cover selected would be lift-on, lift-off lid design and the cars could still be rotated to equalize wheel wear (11).

The conceptual system envisaged a labour requirement but this accounted for a minimal proportion of the overall costs. The anticipated cover maintenance costs were higher than those of the steel covers due to the less durable properties of fibreglass.

The operating cost estimates ranged from $0.57 to $1.18 per tonne of coal shipped and would increase the shipping costs by 3 to 6 percent (Table 12).

Uncertainty surrounds many of the operating costs associated with the various coal dust mitigation measures. This is especially true for the rigid cover systems, since no system presently operates on a mixed fleet of cars as operated in Canada. Assumptions with respect to unsubstantiated costs account for the variation in the cost estimates produced by different investigators. An attempt has been made to indicate the influence of changes in the values of the different cost components on the overall costs, Table 12. The dominance of particular factors is indicated as a percentage of the total cost.

6.2 Benefits Derived from Dust Mitigation Measures

A reduction in the amount of coal lost from trains during transport provides a number of tangible and intangible benefits to the coal companies and society. However it is difficult to quantify many of these benefits since there are no accurate measurements available as to the percentage of coal lost from unsprayed and sprayed cars and there is no automated cover system operating in a scenario similar to the complex western Canada coal transport network. The benefits in previous reports (11), (18) are derived using widely differing assumptions many of which are virtually unsubstantiated.

The major tangible benefit provided by dust control is the reduced loss of coal and therefore the greater tonnage of coal delivered to the ports. Through implementation of dust control measures the mining companies derive higher revenues in proportion to the increment in coal delivered. Canada also derives increased export earnings from the savings. This coal is valued at its sales revenue which varies depending upon market conditions.

The coal industry in western Canada rejects the use of unsubstantiated emission factors, however, if one accepts that between 0.5 and 1.8% of a coal load may be lost from untreated cars during a typical journey of 1100 km from a Western Canadian coal mine to the terminal, then potential revenue losses could amount to between $0.30 and $1.08 per tonne of coal transported, assuming a coal price of $60 per tonne. Mitigation measures will then be cost effective if they can reduce the dust losses while keeping the cost of the controls below the costs associated with coal lose. The value of the "loss savings" will depend upon the level of uncontrolled and controlled dust emissions, both of which remain unquantified for chemical spray systems.

In addition to the revenue savings, the following benefits are also provided by coal dust control:

(i) lower soiling damages as a result of decreased coal losses (note that the cost of cleanup of soiling damage has not been included in any of the aforementioned cost estimates);

(ii) a reduced potential for industrial cross-pollution at sites en route. Concern has been expressed by certain pulp and paper producers that soiling of their finished pulp by coal dust could affect their product quality;

(iii) enhanced visibility. A dusting coal train detracts from the visual beauty of the scenery en route;

(iv) fewer citizen complaints re nuisance coal dusting incidents.

6.3 Other Control Options

Other options than chemical sprays and permanent covers have been suggested to solve the dusting problems. These systems have not been subjected to extensive cost analysis, however, Appendix A lists the suggested options and describes their advantages and disadvantages.

6.4 Conclusions re Costs and Benefits

Dust abatement provides the tangible benefit of increased coal sales revenues as well as other less tangible benefits, such as decreased soiling, lower industrial pollution and decreased citizen concern. Insufficient data exist to permit a meaningful evaluation of these less tangible benefits, however the savings resulting from the use of the existing spray systems could range from zero to approximately one dollar per tonne of coal-transported, depending on by how much chemical spraying reduces dust loss (as compared to the cost of spraying).

Currently spray systems are assessed as the least expensive means of dust control with the estimated operating costs ranging between $0.16 and $0.34 per tonne of coal transported. The cost of control using rigid cover systems is higher: the probable cost for steel hinged-cover systems is estimated to range between $0.88 and $1.31 per tonne and fibreglass lift-off covers from $0.57 to $1.18 per tonne. The lack of an operational cover system for the Canadian scenario introduces a high degree of uncertainty with regard to technical feasibility, capital and operating cost estimates for rigid cover systems.

While cover systems are currently assessed to be more expensive to operate, a properly designed rigid cover will provide a more effective means of dust control. However, it is concluded that further engineering studies are required to develop conceptual design alternatives for car cover systems, in order to assess in more detail the associated capital and operating costs for cover systems (34). The variation in the cover system cost estimates, being in the range of $ 0.57 to $1.31 per tonne of coal carried, reflect the uncertainties and gaps in the knowledge base.

The efficiency of the existing spray systems in reducing dust losses should also be studied to determine how cost effective these systems are and whether permanent covers could provide further coal loss reductions to offset the additional costs involved in their use.

7 DISCUSSION AND CONCLUSIONS

Since the early 1970's, the coal producers in western Canada have made major strides in reducing the emissions and the impacts of fugitive coal dust from their loaded coal trains. This has been due primarily to the widespread introduction in 1975, of chemical sealant spray dust control technology. However, each year a small number of "heavily" dusting loaded and empty coal trains continue to occur, primarily along the rail corridor through the Fraser Valley. Consequently nuisance soiling is still a problem in some communities in southern British Columbia and in 1985 the first public concerns about fugitive dusting were raised by two communities along the northern British Columbia transportation corridor which began operation in 1984.

In reviewing all of the coal dust mitigation measures which have been suggested for loaded coal trains, it is evident that the existing dust control technology, using sprayed chemical sealants, is the control measure preferred by coal producers and is likely to remain so for at least the near future. Therefore, the minimum requirement for fugitive dust control is a chemical sealant spray system installed at each coal load-out, as was agreed in 1975 between government and the coal producers. Each of these spray systems should incorporate the best available spray technology and be capable of covering each coal car with an adequate quantity of chemical dust suppressant.

However, spray system performance consistency is a problem for some of the coal producers. The occurance of "heavily" dusting loaded trains through Agassiz, B.C. has been due to the inconsistent dust control performance of chemical spray systems. This lack of consistency was demonstrated during 1984. During six of the months of 1984 no "heavily " dusting trains were observed in Agassiz, whereas 17 of the 26 train observations (65%) were recorded during two months, January and July (7 and 10 respectively). Virtually all of the July incidents were reported as due to chemical formulation problems. During the other months of 1984 various factors caused the dusting problems. Consequently, some improvements are required at the mines involved to achieve more consistent coal dust control and to eliminate "heavily" dusting trains.

Another example of inconsistency with respect to dust control is the variability of crust retention. Marked differences in crust retention are often noted from car to car and from train to train. During wet weather high crust retention may not be necessary, but during dry weather, cars with poor crust retention or cars that have not been sprayed are known sources of fugitive dusting en route.

Trains from every mine have been observed to achieve high levels of crust retention. Therefore considering the successes achieved, improvements in crust retention

for trains where dusting is a problem should be possible. In order to meet the objectives of improved dust control consistency and a reduction in "heavily" dusting trains, breakdowns of sealant spray equipment which can lead to inconsistent performance must be reduced in frequency. Suggestions for the optimum design of a sealant spray system and for improvements which may reduce problem dusting are listed below.

7.1 Chemical Spray and Load Levelling Installations

In order to improve system performance consistency and dust control the following design features and operation procedures are recommended to optimize spray facility operations. The measures listed below are based on the findings of laboratory tests, field monitoring studies and observations of the western Canada coal-transportation network by various investigators over the last decade.

A. Maintenance and Training

Observations have indicated that certain spray application facilities were neither adequately inspected nor maintained. Coal mining companies should implement, and adhere to, thorough maintenance schedules for their spray systems to ensure proper operation of the mixing equipment, spray nozzles, spray headers and load levelling devices. Spray headers and nozzles should be purged after a train has been sprayed. They should also be tested, the spray patterns verified and the mixed solution concentration checked when the first car of each train is loaded and sprayed. Load levelling devices should be checked for correct operation when the first car of each train is loaded.

Observations have shown that operator error can result in improper loading and spraying. Where they do not already exist, companies should implement training programs for load-out operators. These programs should not only include the proper operating procedures for chemical spray systems and load levelling devices but should emphasize the environmental importance of the operator's tasks. The importance of correct equipment operation for successful crust retention performance and high dust control efficiency should be stressed in these training programs.

B. Spray Facility Design

For maximum crust retention and performance consistency, chemical spray systems should include the following design features:

- spray patterns that are protected from distortion by wind;

- freeze protection measures or equipment on all piping, headers and nozzles in order to prevent the freezing of fluids during the worst winter conditions;
- nozzle patterns that are designed to coat all of the exposed coal surface on every car;
- sprays that turn on and off rapidly in order to effectively coat all critical coal surfaces near the front and rear of each car;
- mixing and flow-metering equipment which will ensure the uniform application of evenly mixed sealant chemicals, of the desired concentration, over all coal surfaces irrespective of train speed through the load-out.

C. Load Levelling and Compaction Devices

Most chemical sealants have demonstrated an inability to form stable crusts on sloped or irregular surfaces, therefore each spray system should be complimented by an effective load levelling and compaction device capable of obtaining the flattest possible profiles on loaded coal cars. Side ridges, humped profiles, and steep end-slopes should be significantly reduced or eliminated prior to spraying. Load levelling and compaction devices should be designed to adjust (or be adjusted) to the height of all sizes of coal cars being loaded in order to reduce profile distortions.

If coal is deposited on car sills during loading, a sill-sweeping device should be added to the load-out to remove this loose material.

D. Car Respraying Systems

Spray system breakdown and other errors during the application of chemical sealants to loaded coal cars can result in unsprayed cars and can lead to "heavily" dusting trains en route. Coal shippers should devise methods to ensure that all cars in their loaded trains are coated with an adequate quantity of sealant. One method of accomplishing this is to back a train into the spray unit so that cars missed during the first pass can be resprayed. Where this is not possible a mine-site spray system should be equipped with two separate spray units.

For the two spray setup, each of the two spray units, a primary and a secondary, should employ separate pumping equipment, piping, spray headers and nozzles. The spray headers and nozzles of the secondary spray unit should be physically separated from the first spray unit and at sufficient distance to allow an operator to identify problem cars and to activate the second spray unit. An operator should inspect each car as it is sprayed; all cars identified by an operator as unacceptable (unsprayed and partially

sprayed cars) should be sprayed by the secondary spray unit. Both spray units should conform to the design criteria listed herein and the secondary spray unit should have access to sufficient chemical sealant to spray an entire train set. In the event of the total failure of the primary spray unit the secondary unit will also serve as a complete standby spray system.

E. Chemical Sealant Research

Operating experience and research indicate that improved crust retention peformance from chemical spray systems can result if spray systems are operated using the optimum techniques (spray concentrations, solution volumes per car, application methods and crust curing times) for given ambient conditions. Chemical sealant suppliers should establish the optimum conditions for using their dust suppressants and the coal mining companies should endeavour to employ these optimum procedures when spraying their coal trains. In addition, it is suggested that the mining companies and chemical suppliers continue evaluating new and improved sealant chemicals and other methods of improving crust retention performance.

7.2 Crust Retention Goal

The percentage of crust-cover-remaining or crust retention (as measured by the observed ratio of crust-area-remaining to the total surface area of the load profile), on cars arriving at the unloading terminal is the present quality control method for estimating spray system performance. A performance goal of 85% crust retention was agreed to by the coal mining companies involved in the original performance tests in 1975 (2).

The overall objective is to eliminate heavily dusting trains. Depending on weather conditions, a crust retention of 85% per car generally appears to achieve this objective. Environment Canada and the British Columbia Ministry of the Environment consider 85% crust retention on each car to be the minimum requirement for control purposes. This goal is achievable with conventional spray equipment.

Since crust retention is not an absolute indicator of coal-dust emission control, in areas where a fugitive coal dust problem persists, the coal companies involved should work toward a goal of dust elimination rather than crust retention in order to prevent nuisance coal dust impacts.

The coal mining companies must continue to implement methods of improving the consistency and overall performance of their dust control systems in order to

eliminate "heavy" dusting trains and to reduce dust emissions. They must strive to achieve a level of dust control that will reduce coal dust emissions to a level that is acceptable to communities and citizens.

7.3 Performance Monitoring

Mining companies shipping coal to terminals in western Canada should implement routine self-assessment programs to determine the performance of their dust control systems and the effectiveness of system improvements. Self-assessment programs should include quality assurance checks of the crust retention on coal cars arriving at end terminals. Observers at end terminals should check and record a representative number of coal cars and trains sets in order to ensure that effective crust retention, i.e. 85% minimum, is being achieved.

For those operators having persistent dusting problems, monitoring is recommended. Monitoring would be carried out under the two categories of compliance and environmental monitoring. The degree of monitoring required in each category would increase or decrease depending on the magnitude and persistence of a coal dusting problem.

Along a rail route where nuisance soiling from fugitive coal dust is an identified problem, it is recommended that the coal mining companies involved implement a program to assess dust emissions by visual or other means. The techniques employed must provide a means of recording emissions and of rapidly reporting "heavily" dusting trains to the coal mine operators.

It is further recommended that when and if a train leaving a mine site has not been properly sprayed it be reported immediately to the railway company involved so the train crews can monitor the trains performance and reduce speed to limit fugitive dusting if so required.

The implementation of monitoring programs should be developed in consultation with the relevant government agencies.

7.4 Overload Reduction - Gouging

Where overload reduction by "gouging" the surface profile is still practiced, the companies involved should implement procedures to level and spray all cars whose loads have been corrected.

7.5 Coal Car Height

The varying heights of coal cars may influence the optimum operation of

loading chutes, load levelling devices and spray equipment. Therefore, to aid the southeast B.C. coal producers in particular, the railway company should endeavour to group cars of the same height, either as complete train sets or as groups of similar cars within the same train. This practice will simplify the loading operator's task and should contribute to attaining flat coal profiles on a more consistent basis.

7.6 Car Cleaning Systems - The Empty Train Dusting Problem

Loose coal on exterior surfaces of "empty" cars can be a source of wind-blown coal dust. Each coal terminal should install and operate a car cleaning system to clear sills and exterior car surfaces of loose coal prior to the cars commencing the return journey to the coal mines.

However, an exterior car cleaning system will not remove coal from the inside of dumped "empty" cars. In southern B.C. in particular, the coal remaining in the bottom of cars after dumping, referred to as carry-back, (either dry or frozen-coal carry-back) can be a source of fugitive dust.

The coal mining companies and the terminal operators should continue their investigations of side-release agents, thaw sheds and other methods for improving car dumping to eliminate coal carry-back and empty car dusting. The feasibility of air or water jets designed to remove coal from the inside of cars should be evaluated.

7.7 Reduced Train Speed

It is recognized that the operation of mechanical dust control systems, regardless of the design and maintenance procedures employed, can not be perfect and that the sealant spray technique does not provide 100% dust control. In the event that inadvertent failures of control systems result in "heavily" dusting trains it is recommended that the railway companies consider the implementation of a policy that requires all "heavily" dusting trains to reduce speed in communities where dusting will cause a nuisance pollution problem. This is particularly true for "heavily" dusting empty trains.

7.8 Coal Car Covers

One of the most effective methods of containing coal cargo within railway cars, and thereby eliminating the related problems of coal product loss and nuisance dusting from both loaded and empty trains, is to install car covers. A unique automated cover system for coal trains is in use in North America but there is no off-the-shelf system currently available for retrofitting to the complex western Canada coal-

transportation network. Extensive reconstruction of existing facilities would be required to accommodate present cover designs.

Considering the technological problems, the uncertainties with respect to operating costs, and the subsequent resistance to car covers within the coal industry, it is unlikely that any coal-car cover system will be operating in Canada within the foreseeable future.

However, there may be long-term advantages to be derived from this technology, and therefore the coal mining industry is encouraged to continue the investigations begun by Environment Canada into automated cover technology. An extensive prototype design, construction and testing program would be required in order to develop a cover system which could be used in western Canada (34).

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APPENDIX A

ADVANTAGES AND DISADVANTAGES OF THE VARIOUS TECHNIQUES FOR CONTROLLING WIND-BLOWN COAL DUST FROM TRAINS

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ADVANTAGES AND DISADVANTAGES OF THE VARIOUS TECHNIQUES FOR CONTROLLING WIND-BLOWN COAL DUST FROM TRAINS

A.1 Introduction

The mitigation measures and control options for coal dust were discussed in section 5, the perceived or recognized advantages and disadvantages of the principal technology options only are listed below.

A.2 Technology Options - Railway Companies

A.2.1 Uniform Car Design or Grouped Coal Cars

The reason for a uniform car design or the grouping of cars of the same size is to allow loading of cars of the same sill height and capacity within one train set.

Advantages:

- may reduce train loading times;
- will aid flat profiling in individual cars;
- car grouping would require no capital investment;
- a new car design could increase coal pay load;
- a new car design could improve coal dumping and reduce coal carry-back.

Disadvantages:

- a sizeable fleet of mismatched cars are in service, therefore the retrofit of extensions or reductions to cars in order to introduce uniformity within the fleet would be expensive and impractical. Introducing cars of a new design would add another car type to the present mixture;
- consensus on a "best" design could be difficult;
- new designs or car grouping are not control measures in themselves, but only act to supplement or improve the chemical spray dust control systems;
- the degree of dust control improvement achieved by an improved car design could be marginal and not warrant the expense;
- grouping cars could add scheduling problems and possible round trip delays.

Cost:

A retrofit program to bring all cars in service up to the same design is unlikely because of the large number of cars that would

have to be rebuilt or removed from service. New cars introduced into service could be built to a universal design, particularly with respect to sill height, and it is unlikely that building cars to a universal design would add appreciably to new car construction costs. Grouping cars of the same design could add to overall operations costs.

A.2.2 Aerodynamic Modifications To Cars

Advantages:

- additions to cars could reduce the wind over the coal surface and thereby reduce fugitive dusting;
- no per car materials cost once installed;
- no additional operators required.

Disadvantages:

- unproven, research required to test the feasibility;
- extra car maintenance will be required;
- a mismatched fleet of cars complicates the retrofit;
- the structural additions must be strong enough to withstand the rigors of the loading/unloading procedures;
- the structural additions could hinder coal loading/unloading. In particular the unloading of frozen coal could present a major problem if new structures span the top of a car.
- any structural additions must not interfere with loading/unloading equipment at the mine and at the terminal
- the weight of the additions would add to car tare weight and would reduce the coal load;
- a chemical spray or other dust control system may still be required if dust control is not complete;
- coal cars must be removed from service during the retrofit.

Cost:

Depending upon the materials used and the design selected, the capital cost of the structural additions should be low, although installation and demurrage charges during the retrofit program would increase the total cost.

A.3 Dust Control Technology Options-Coal Mining Companies

A.3.1 Flat Load Profile - Load Compaction

Most evidence supports the theory that a very flat, compact coal profile is required for adequate sealant crust retention. Most mines now employ load levelling devices but designs vary and some are more effective.

Advantages:

- improved crust retention will improve dust control;
- no per car materials cost.

Disadvantages:

- a completely flat profile is difficult to achieve without stopping the train while loading;
- research into the "best" load leveller design is required. Since all coal load-outs are different, no optimum design may be possible;
- a flatter profile may not necessarily ensure adequate dust control unless accompanied by other system improvements;
- a new or redesigned load-out may be required to accommodate the leveller;
- the optimum load leveller may require a full-time operator;
- extra maintenance may be required for an optimum load-leveller;
- a uniform car design may be required in order to achieve a flat load profile.

Cost: The capital costs would be high if the redesign of the coal load-out is required. A full-time operator may be required.

A.3.2 Sprays. Spray systems and modications to spray systems have the following features in common:

Advantages:

- systems for applying fluids to coal trains are in place at all of the major coal exporting mines in western Canada;
- trained operating and maintenance personnel are available;
- no modifications to rolling stock are required.

Disadvantages:

- close to 100% fugitive dust abatement may not be possible for any spray system;

- winter freeze-up of the spray equipment is a problem and protection must be provided;
- a secondary spray system may be required to coat any unsprayed cars;
- a coal load levelling system is required;
- spray installations require frequent maintenance in order to maintain dust control performance levels;
- sprays do not prevent the build-up of snow, ice and rain in the returning cars;
- spray fluid weight supplants coal weight;
- mine site spray facilities do not solve empty car dusting problems;
- high winds can hamper proper spray application;
- a spray operator may be required to monitor system performance.

A.3.2.1 New Chemical Sealants

Advantages:

- chemical storage and handling systems are in place;
- crust retention averages could be improved.

Disadvantages:

- new chemicals may not significantly improve crust retention;
- performance would still be dependent upon operating efficiency and environmental factors;
- improved load levelling devices and other system improvements may still be required;
- research into the effectiveness of new chemicals is required;
- new chemicals may damage rail cars;
- per car materials cost (chemical costs) could escalate.

Cost: For a 5% solution, 9 litres (2 gal) of commercial latex sealant per car, the materials cost are approximately $8 to $12 per car, new chemicals could escalate that cost.

A.3.3 Improved Chemical Sealant Application Techniques

Advantages:

- increased crust retention and increased dust control could result;

- low cost depending on the system changes required;
- no additional materials cost;
- a secondary spray system would be a step toward eliminating "heavily" dusting trains.

Disadvantages:

- positive results are unproven since no optimum design is available;
- additional maintenance would likely be required if a more complex spray apparatus or a second spray system were installed.

Cost: The addition of new, more complex equipment would increase operation and maintenance costs.

A.3.4 Increased Chemical Sealant Concentration

It has been suggested that for certain chemicals increasing the concentration of the commercial sealant in the present spray solutions and emulsions could improve crust retention.

Advantages:

- increased crust retention would increase dust control;
- no additional personnel required;
- quick implementation;
- no additional maintenance required.

Disadvantages:

- increased per car materials cost;
- may not provide sufficient additional dust control to justify the increased cost per spray application;
- research into the effectiveness of high concentration sprays is required;
- higher concentration chemical sprays may increase the damage to rail cars.

Cost: The coal mining companies spend $8 to $12 per car to spray a train with commercial sealants which cost approximately $0.90 per litre ($4/gal). If the present quantity, 9 litres (2 gal) per car, were doubled or tripled, the cost of materials would increase to $20 or $30 per car.

A.3.5 Chemical Sprays - En Route

Advantages:

- a chemical spray applied en route after load settling may improve overall dust control;
- technology and trained operating personnel are available.

Disadvantages:

- there are no spray systems in place at en route sites;
- indiscriminate spraying could damage rail cars and engine units, therefore spray headers must be designed to swing away from tracks. This swing-away requirement would complicate design and increase maintenance costs;
- maintenance would be required for each spray unit;
- full-time operation and maintenance personnel would be required;
- per car materials cost (chemical costs) are escalating;
- sprayed fluids add to total car weight;
- collective agreement would be required by all of the mining companies using the spray systems;
- could increase the overall round trip time if spraying must be performed at lower than normal train speeds;
- research is required to ascertain the best en route site locations.

Cost: Capital would be required to build the en route spray system or systems, but this cost would be shared by a number of coal mines. Maintenance costs would be higher than for the present mine site facilities because of increased usage. Full-time operating personnel would be required at en route sites unless a fully automated system were developed.

A.3.6 Permanent Covers. Automated cover systems employing a hard or permanent lid would have the following features in common:

Advantages:

- covers represent an effective solution to the fugitive dusting problem and may be the only system capable of close to 100% dust control;
- supplemental dust control systems such as chemical sprays and load levellers are not required;

- covers will eliminate the build-up of snow, ice and rain in returning cars;
- trains would not be required to reduce speed;
- covers represent a solution to "empty" car dusting problems;
- permanent covers do not create a waste problem;
- once installed there is no per car materials cost.

Disadvantages:

- covers may not be able to withstand the rigors of the coal handling network without considerable maintenance;
- the weight of the covers will reduce the coal load in each car;
- the "mixed bag" of coal cars now in service will hamper the development of a universal cover and cover handling system;
- frozen coal carry-back may still be a problem due to inherent moisture;
- there exists a possibility of spontaneous combustion;
- damaged or jammed covers will cause loading and dumping delays and increase round trip time;
- coal build-up on car sills may hamper lid sealing;
- winter icing may hamper cover opening and sealing;
- a fail-safe lid locking mechanism is mandatory and the possibility of cover loss may increase insurance costs;
- there will be a considerable lag time to design, build and install the systems;
- any latches and fittings must not interfere with loading or dumping mechanisms;

For additional detail on cover systems, see Reference 9.

Note: The requirement for a fail-safe locking or securing mechanism must be stressed. Without such devices covers of any design are unacceptable.

Cost: Refer to the cost discussions in section 6.

A.3.6.1 Hinged-Covers (Figures A-1 and A-2)

Advantages:

- a functioning automated system has been in use in North America since 1975;

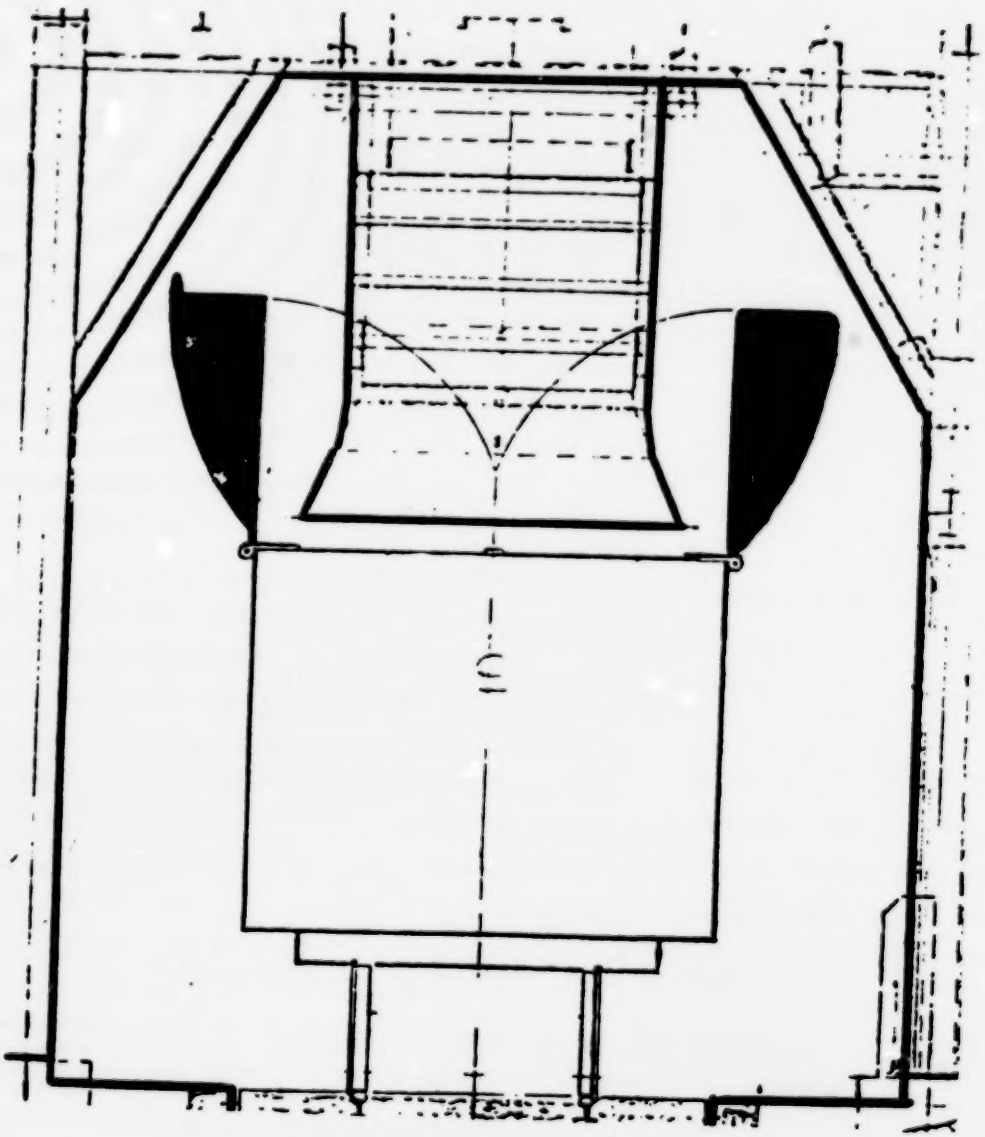


FIGURE A-1 CLAM-SHELL HINGED-COVER - CONCEPTUAL DRAWING

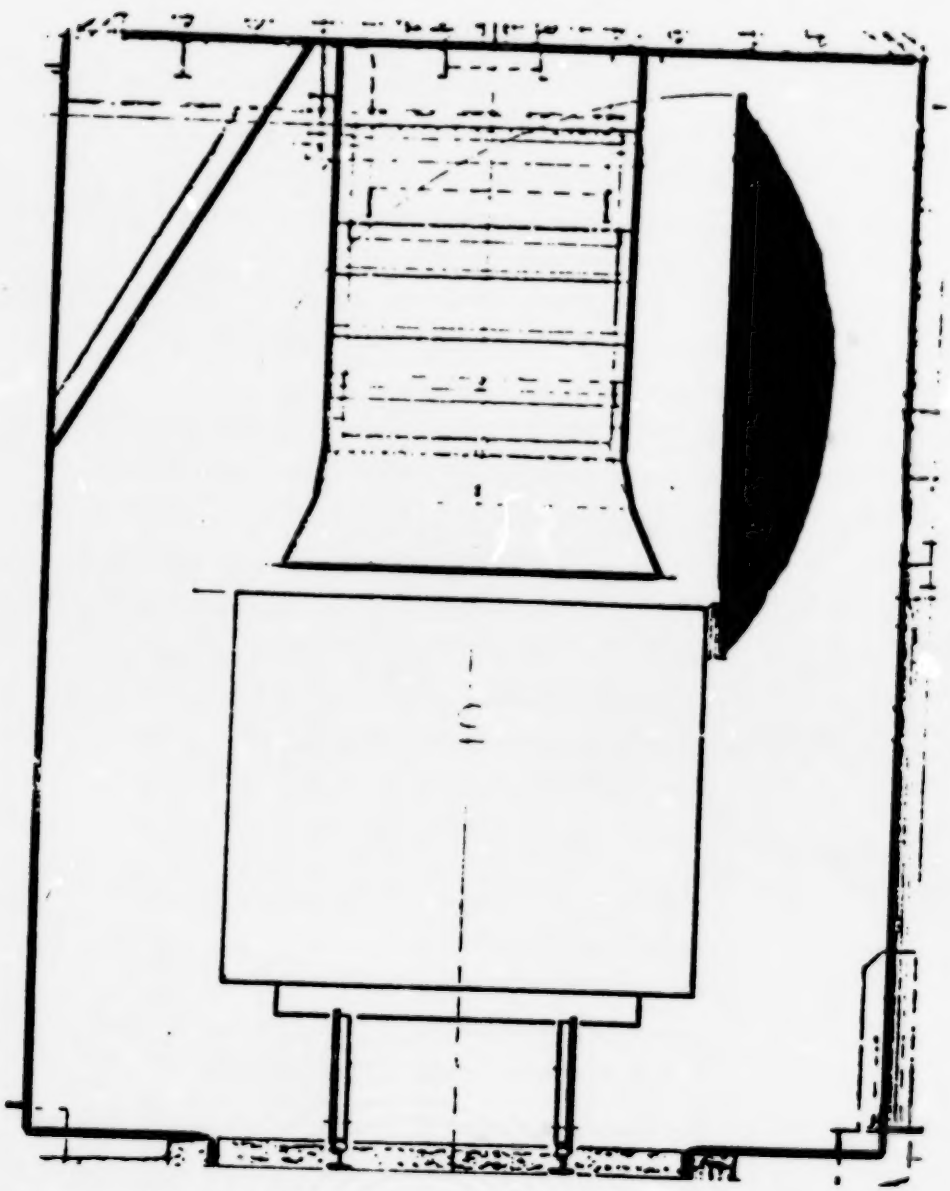


FIGURE A-2 SINGLE-SIDE HINGED-COVER - CONCEPTUAL DRAWING

- no additional equipment is required at the end terminal;
- the cover handling apparatus at the mine load-out is of simple design and relatively easy to maintain.

Disadvantages:

- because of incompatibilities with present rotary-dumpers and load-out facilities, major modifications to existing facilities would be required;
- mismatched rolling stock will complicate the development of a universal cover design;
- not all dumpers rotate in the same direction therefore the operation of cars with lids hinged to one side will cause difficulties;
- car rotation for uniform wheel wear will be complicated;
- a hinged-lid car may only be used by companies with a lid opening system.

Cost: In 1975 the prices for the components of the one functioning automated cover system using hinged lids were listed as: covers, $4500 (U.S.) per car ($0.5 million per train) and the unlatching system $78 000 (U.S.) for an installation where the loading system required no restructuring. A 1981 estimate of the lid costs was $8 000 per car.

A.3.6.2 Removable-Lids (Figure A-3)

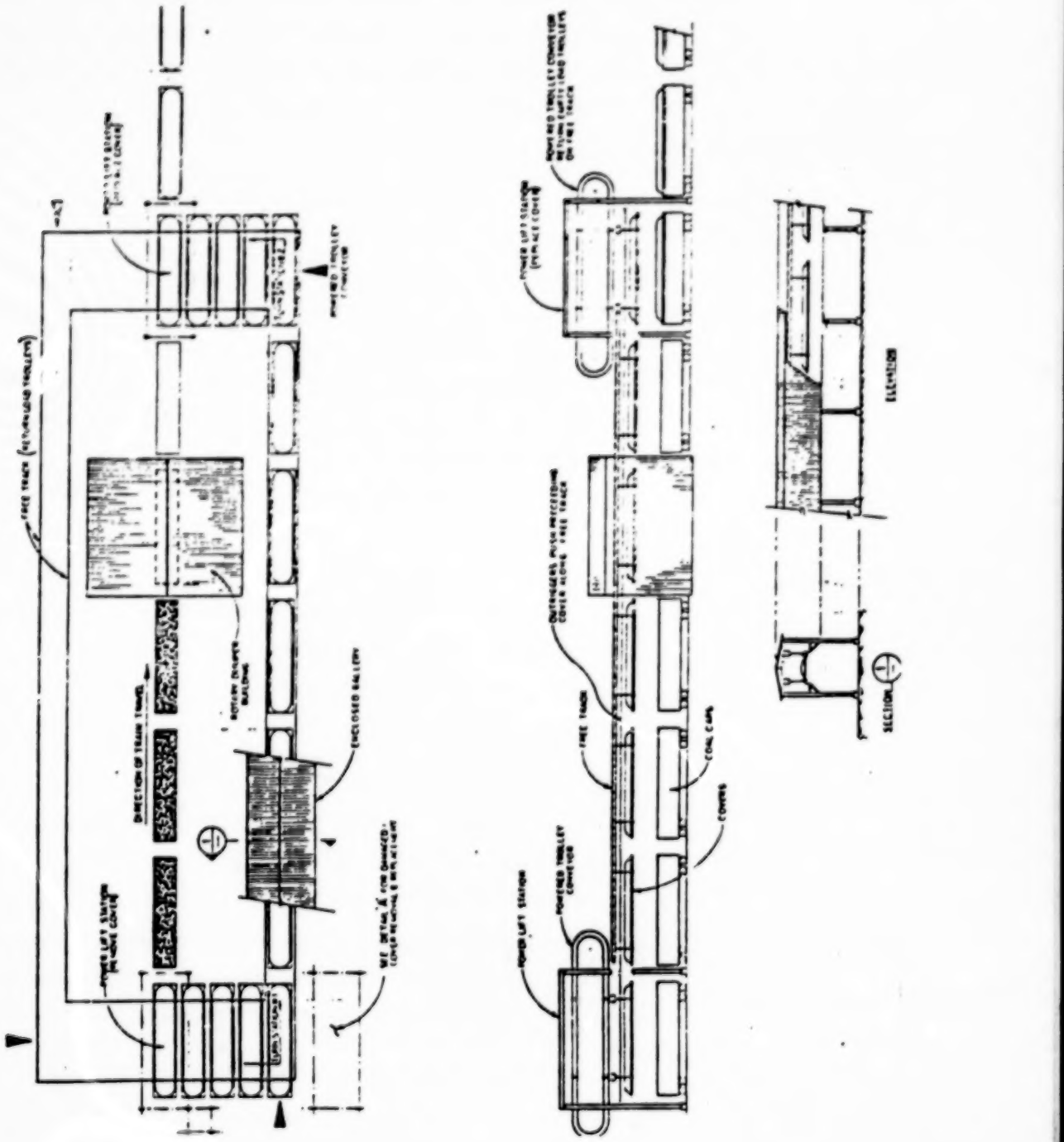
Advantages:

- this style of cover would be compatible with the existing loaders and unloaders;
- no restriction of loading operator's view;
- covers can be removed so that cars may be used by shippers who do not have a cover removal system.

Disadvantages:

- unproven technology, no automated system is available;
- cover removal and replacement systems are required both at the mine and at the end terminal;
- because covers must be removed and replaced, the handling systems are more complex than for other cover systems;
- because of the handling system complexity, the maintenance requirements will be greater than for other cover systems;

FIGURE A-3 LIFT OFF COVER-HANDLING SYSTEM - CONCEPTUAL DRAWING



- The lack of permanent hinges means that fail-safe hold-down devices are more important for this type of cover.

Cost: Complex cover removal systems are required at both the coal mine and at the end terminal, therefore the capital investment plus maintenance costs for this type of cover system will be greater than for hinged or roll-back cover systems.

A.3.6.3 Roll-Back Covers (Figure A-4)

The lid components of this style of cover would be designed to roll back into an end or side housing during the loading or unloading operations.

Advantages:

- cars with the lids stowed may still be used by companies with no lid opening system;
- the chance of lid loss is reduced with this style of cover;
- the unlatching mechanisms would be minimal therefore this type of cover would be compatible with most loading/ unloading facilities;
- this style of cover would more easily adapt to a mismatched fleet of cars.

Disadvantages:

- no proven technology exists;
- the covers would be intricate, multi-sectional devices, thus cover maintenance would be high;
- the intricate covers would be readily susceptible to damage from rough use;
- cover hardware and the housing must not project beyond the present maximum dimensions of a car;
- there is a greater probability of cover jamming especially from ice and snow accumulation;
- the cover may require power to open.

Cost: Because of the intricate nature of the covers, the per car installation costs would be higher than the other cover types, but the ground installations should be the least expensive of all the cover systems.

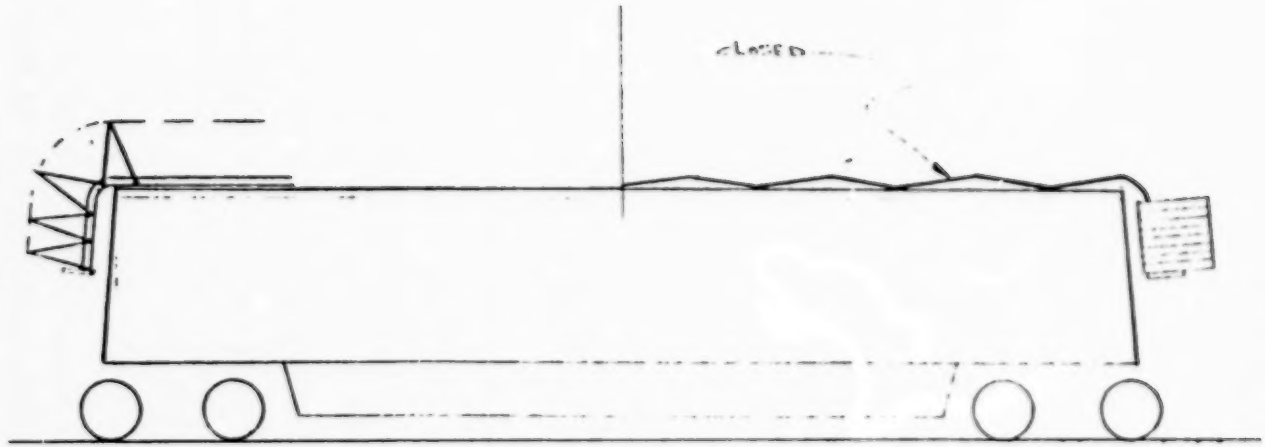


FIGURE A-4 ROLL-BACK COVER - CONCEPTUAL DRAWING

A.3.7 Soft Once-Only Covers

Advantages:

- the displaced cargo weight due to cover weight would be lower than for any other cover system;
- coal cars may still be used by shippers with no cover handling system;
- less danger from en route cover loss.

Disadvantages:

- because the covers are disposable, there would be a materials cost per car;
- there is no technology available. A rugged cover material and an automatic tie-down or sealing system are required;
- disposable covers would be a source of waste;
- since covers are disposed of at the end terminal, this style of cover does not solve the "empty" car dusting and other returning car problems;
- damaged covers and hence dusting cars are more likely than with other lid systems;
- depending upon the cover hold-down system employed cover removal at the end terminals could cause delays.

Cost: Several large mineral mines employ 2 or 3 operators to hand cover their ore cars with woven plastic covers. The cost per car, exclusive of manpower cost, is approximately $25.

A.3.8 Briquettes. A method of reducing the amount of fine coal available for wind entrainment would be to briquette the coal, or otherwise compact the coal into pieces too large to be entrained by all but abnormally high winds.

Advantages:

- no additions to the railway rolling stock are required;
- the existing coal handling equipment should be able to cope with the briquettes. Little additional equipment would be required;
- there are no per car materials cost.

Disadvantages:

- a briquetting facility must be built at each mine;
- coals may not easily briquette;
- end users may require un-briquetting facilities to render coal to its original form;

- briquettes could break during handling and shipping and create fines which would dust;
- any substance added to the coal to produce the briquettes must not affect the properties of the coal as required by the end user.

Cost: The capital cost would be high to build briquetting facilities at every mine.

A.3.9 Water Spray - En Route

Advantages:

- simpler than a chemical spray system, therefore lower maintenance;
- should eliminate emissions at problem locations;
- the sprays do not damage rail cars;
- low per car materials cost;
- no speed reduction is necessary during spray operation.

Disadvantages:

- there are no systems now in place along the rail lines;
- operating personnel or automation would be required at each en route location;
- maintenance would be required for each unit;
- many systems could be required to protect all potential dust zones;
- fluids added en route would increase the total loaded weight of the cars;
- collective agreement would be required by all companies using the route;
- water availability may cause problems in certain locations.

Cost: Water sprays have only a short range effectiveness, therefore there could be a requirement for over 30 spray units along the rail corridor in southern British Columbia if each community along the route requested a system for dust protection through their town. The estimated capital cost of a chemical spray facility is $125 000 to $250 000, water spray systems will cost less but the defrosting, pumping and the equipment for automation will influence the per

unit cost. The capital investment required for a large number of spray stations may be unacceptably high.

A.3.10 Coarse Coal Topping

Advantages:

- no additions to cars would be required;
- no additional per car materials cost.

Disadvantages:

- the effectiveness of this technique will vary with the thickness of the coarse coal layer and the size of the coarse coal;
- there may not be sufficient coarse coal (lumps greater than 9 mm, 3/8 inch) in a product stream to provide a blanket of large coal over the load in each car;
- coarse coal silos and handling equipment may be required;
- highly friable coarse coal will continue to break into finer pieces even after separation;
- some fine coal could adhere to the larger pieces of coal and thus would be available for wind entrainment;
- this technique does not solve the dusting and snow buildup problems associated with "empty" cars.

Cost: Capital investment would depend on the coarse coal handling and storage equipment required at each mine.

A.3.11 Water Spray at Mine Load-Out

As a primary, mine site, dust abatement system:

Advantages:

- low per car materials cost;
- the sprays do not damage rail cars;
- flood spray bars can be built high enough to allow free passage of the engine units, therefore maintenance requirements are less than for chemical systems.

Disadvantages:

- in hot, dry weather water sprays may only effective for a few kilometres.

Cost: Capital, operating and maintenance costs would be lower than for chemical spray systems, however, because of their limited effectiveness, water sprays would not be installed as primary, mine site, dust control systems unless transport distances were very short.

A.3.12 Remove Coal Fines

Advantages:

- no per car materials cost;
- if the existing coal preparation plant separates fine coal, no major modifications would be required.

Disadvantages:

- even after separation the highly friable, coarse coal would break apart to create additional fines during handling and en route;
- because of the quantity of fines in western Canada coal they cannot be discarded, a market for fines must be created in the vicinity of the coal mine. If no market is found, the technique is economically unacceptable;
- separate handling facilities for coarse and fine coal would be required.

Cost: It is unlikely that a market for a large quantity of coal fines will be found in the area of most coal mines therefore the lost product revenue that would result from this practice would be unacceptably high.

A.4 Control Options - Coal Terminal Operators

A.4.1 Combined Interior/Exterior Car Cleaning

Exterior car cleaning alone does not solve the problem of dusting from coal left inside dumped cars. The total cleanout of "empty" cars will require a combined interior/exterior car cleaning facility.

Advantages:

- will solve both the "empty" car dusting and the coal carry-back problems;
- air jets, as opposed to water sprays, would not add water to coal;
- no per car materials cost

Disadvantages:

- water from sprays directed into upright cars may collect in the bottoms of the empty cars;
- a redesign of the rotary dumpers to accommodate the water or air jets would be required;

- there would be an interruption of the coal/rail network during installation;
- water sprays could result in winter freeze-up problems in the dumpers;
- car cleaning does not alleviate loaded car dusting problems;
- could increase coal moisture content;
- interior car cleaning would not solve the problem of rain and snow build-up in returning cars.

Cost: The initial cost could be high if major modifications to each rotary dumper were required.

A.4.2 Thaw Sheds or Side Release Agents

Advantages:

- if complete car dumping is achieved then these techniques could solve the "empty" car dusting and coal carry-back problems;
- additional equipment requirements for side release agents are minor.

Disadvantages:

- the capital cost for a thaw shed is high;
- the cost effectiveness of side release agents is still under evaluation;
- do not alleviate loaded car dusting problems;

Cost: The preliminary estimate for side release chemicals is $30 per car, therefore the cost of coating every car in every coal train arriving on the west coast with a side release chemical would be prohibitive. The investment and operating costs for a thaw shed are high.

APPENDIX B

CHEMICAL SEALANTS AND BINDING AGENTS FOR COAL DUST SUPPRESSION

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CHEMICAL SEALANTS AND BINDING AGENTS FOR COAL DUST SUPPRESSION

B.1. Introduction

Many chemicals are marketed as or are being used as dust suppressants. A list of some of these chemicals is provided, Table B.1 (31).

WARNING: Not all of the chemicals listed herein have been tested for their crust retention (or surface agglomeration) capabilities in coal train service. Therefore, since the optimum performance levels and cost effectiveness for many products are not known, no attempt has been made to rank the products in the list provided. Potential users are advised to request test data from the manufacturers. Other chemicals have been tested since this list was prepared.

The mention of product names in this report does not represent an endorsement by Environment Canada.

TABLE B.1 CHEMICAL SEALANTS AND BINDING AGENTS FOR COAL DUST SUPPRESSION (unranked listing) - EFFECTIVENESS NOT LISTED

UNRANKED No.	Brand Name	Main Base Constituent	Manufacturer or Distributor
1.	Coherex	Asphalt	Witco Chemical Canada Ltd.
2.	GCP Dust Suppressant 200	?	Betz Laboratories Inc.
3.	Coal Cover	Coal/Wax/Plastic	Atlantic Research Corp.
4.	Darex 3333	Latex	W.R. Grace & Co.
5.	EX 11-7	Sulphite Liquor	Diachem Industries Ltd.
6.	Bond-All NJ	Petroleum Resins	Norjohn Contracting Ltd.
7.	Calcium Chloride	Calcium Chloride	Allied Chemicals Ltd.
8.	IPG-60	Gelatine	Davis Gelatine (Canada) Ltd.
9.	M-167.2	Latex	Dowell of Canada
10.	M-166	Latex	Dowell of Canada
11.	Vultex 2-V-5522-B	Latex	General Latex and Chemicals
12.	ICA-16 TRET-O-LITE	Acrylic Copolymer	Petrolite Corp. of Canada
13.	Coal Pile Retainer	Resins	West Chemical Products of Canada Ltd.
14.	Nalco 8820	Latex	Alchem Inc.
15.	AMS 2000	Acrylic Polymer	Arco Chemical Company
16.	Pentron DC-8	Acrylic Polymer	Apollo Technologies
17.	Gamresin WP24	Resin	Gamlen Chemical Co.
18.	Colas Crusting Agent	Asphalt	Flintkote
19.	Micro-Foam	Surfactant	Deter Company Inc.
20.	Compound SP	Latex	Johnson March
21.	Starch Spray	Starch	Industrial Grain Products
22.	M-218	Polymer in Oil	Dowell of Canada
23.	AMS 2010	Asphalt	Arco Chemical Company
24.	Hercobind DS-3	Emulsified Resin	Hercules Inc.
25.	Bindtex	Polymer	Rogers Bros. Ltd.
26.	Dust Ban 8A08	Polyacrylamide	Alchem Inc.
27.	Van Kap 1000 (AMS 2200)	Petroleum Emulsion	Van Waters and Rogers Ltd.
28.	MWR 078 & 082	?	Mine Waste Reclamation Ltd.
29.	Hynate S-1	Surfactant	Mitsui Co.

TABLE B.1 CHEMICAL SEALANTS AND BINDING AGENTS FOR COAL DUST SUPPRESSION (Unranked listing) (Cont'd)

UNRANKED No.	Brand Name	Main Base Constituent	Manufacturer or Distributor
30.	Reclamation Oil	Oil	Cominco
31.	Dust Suppressant 100	Asphalt	Pounder Emulsions Ltd.
32.	Dust Suppressant 200	Asphalt	Pounder Emulsions Ltd.
33.	Dowell M167	Latex	Dowell of Canada
34.	Alchem 63026	Latex	Alchem Ltd.
35.	Acquatain	?	Whitlock Construction
36.	Lignin Derivatives	Pulp Mill Waste	Cominco
37.	Coal Spray 100	Oil	Imperial Oil
38.	Triton CF-10	?	Rohm & Haas Company 1976
39.	Lignosulfonic Acid	Lignosulfonic Acid	
40.	Flintkote SS-1	Asphalt	Flint Kote
41.	Heavy Residual Oil	Oil	
42.	Alchem-Nalco 5WM-493	Latex	Alchem Ltd.
43.	Bitumen	Bitumen	Cominco
44.	Water & Surfactants	Water & Surfactants	
45.	Curasol AC	Copolymeric Plastic	Mackenzie & Feimann Ltd.
46.	Dowell M145	Latex	Dowell of Canada
47.	Cyanaspray	Latex	Cyanamid of Canada Ltd.
48.	Geo Cote 8-4	?	Trans Can Grouters Ltd.
49.	Van Kap 300	?	Van Waters and Rogers Ltd.
50.	DLR-H,S	Acrylic	Rohm & Haas Ltd.
51.	Hot Melt	Slack Wax	
52.	Daratak SP-1065	Polyvinyl Acetate	W.R. Grace & Co.
53.	Everflex GT	Copolymer	W.R. Grace & Co.
54.	Esco M105	?	ESCO
55.	Wax 778	Slack Wax	Imperial Oil
56.	Wax Emulsion	Slack Wax	Imperial Oil
57.	Oil QE2296A	Oil	Imperial Oil
58.	Oil QE2298A	Oil	Imperial Oil
59.	Wax-Oil-Water	Wax	Airth Group

NB Detailed specifications, where available, are presented in Reference 31.

APPENDIX C

COST ESTIMATES - DETAILS

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C.1 PREVIOUS COST ESTIMATES - DETAILS

The industry has not accepted the cost estimates presented in this report nor those presented in the two listed references (11), (18). For reasons of confidentiality the industry has also declined to input control system cost data to this report.

The reports of two investigations into fugitive dusting from coal trains, References 11 and 18, contain cost comparisons of chemical spray systems and permanent, automated, cover systems. These two reports represent the basis for developing the control system cost estimates discussed in Section 6. The underlying assumptions used for each of these two sets of calculations are discussed below.

C.1.1 Ridley Island Study - Cost Comparison

A preliminary cost analysis study carried out in 1980 in relation to potential coal dust problems at the new Ridley Island, B.C. coal terminal compared fibreglass covers and steel hinged-lids to chemical sealant sprays. (18). The assumptions used to arrive at these estimates were as follows:

- Movement of five million tonnes of coal 1 125 km from two coal mines located in Northeastern British Columbia to Prince Rupert.
- Movement was made in 100 car trains, each car having a capacity of 91 tonnes.
- Transportation cost was assumed to be 1.2¢ per tonne km.
- Capital costs were converted to annual costs using a capital recovery rate of 10%, a 20-year life for all port and mine equipment, a 15-year life for steel covers and a 5-year life for fibreglass covers.
- All maintenance costs were assumed to be 4% of capital cost except the steel cover removal system and the covers which were assumed to be 1% and 2% of capital cost respectively.
- Labour costs were based on 1 man hour per train visit at the mine for chemical binders and 6 man hours at the mine and port to remove and replace fibreglass covers.
- Fibreglass covers weigh 680 kg and the automatic removal replacement system adds 4 hours to the loading-unloading cycle time and requires 2 operators, 1 at the port and 1 at the mine.
- Steel covers weigh 1 590 kg and increase the cost of rail car maintenance .6¢ per km travelled as they cannot be turned around.
- Chemical binders were assumed to reduce the carrying capacity of the rail cars by 225 kg.
- Transportation costs were estimated by using the dust control method of chemical binders as a base case and calculating the incremental costs associated with rail car covers.

The "standard case" published in Reference 18 estimated the amortized cost of permanent cover systems to be five times as great as chemical binder systems, however,

the study incorporated certain assumptions with respect to cover system operations which significantly increased the cost estimates for covers.

The key assumption in the case of fibreglass covers was that the lift-off design would require an additional two hours to remove and replace covers at either end of a journey. The authors of the study felt that the additional four hours for a train round trip cycle would result in a requirement for additional rolling stock to maintain the same annual tonnage throughputs. The capital cost of the additional cars was included in the cost estimate for the fibreglass covers and significantly increased the amortized cost estimate for that type of dust control system. However, a cover system which could not operate within a four hour loading/unloading time constraint would be operationally unacceptable. Therefore this cost element was not employed when making the revised cost estimates in Section C.2 of this report.

The cost estimate for the steel hinged-covers in Reference 18 included an assumption related to preferential wheel-wear. Because covers are hinged to one side of a car and dumpers only rotate in one direction, it was assumed that cars could not be rotated, as per normal railway maintenance schedules, to equalize wheel-wear. An "extra rail car maintenance" factor was introduced which significantly increased the steel hinged cover cost estimate. However, since it is possible that a cover system could be designed (or an operational procedure developed) that would reduce or eliminate this economic penalty, the revised cost calculations (Section C.2) include two cost estimates, one with a wheel-wear penalty (the high case) and one without (the low estimate).

C.1.2 Cover Feasibility Study - Cost Comparison

In a study carried out for Environment Canada in 1982, (11) cost comparisons were presented for steel hinged-lids and fibreglass lift-off cover systems in addition to chemical sealant sprays. The assumptions for these estimates were as follows:

- Movement of 10×10^6 tonnes of coal annually 1 100 km form 1 mine in southeast British Columbia to 1 port.
- Movement was made in 100 car unit trains, each having a capacity of 91 tonnes.
- Capital costs were converted to annual costs using a capital recovery rate of 15%, a 15 year life for steel covers, a 10 year life for fibreglass covers, a 20 year life for steel/fibreglass cover handling systems at mines and port, and a 20 year life for chemical spray systems.
- Annual maintenance costs were assumed to be 2% of the capital cost for chemical sealant sprays; 2% for steel covers and 1% for steel cover handling systems; 4% for fibreglass covers and 4% for fibreglass cover handling systems; and 2% for chemical spray systems.

- Labour costs were based on 4 man hours per train for the chemical sealant and fibreglass cover system. No operating labour charges were assumed for the steel cover system.
- Car under-utilization was based on reduced car capacity due to additional car weights: 0.4 tonnes/car for chemical sealants, 2.27 tonnes/car for steel covers and 1.1 tonnes/car for fibreglass covers. The reduced capacity was charged at a rate equivalent to $70 per tonne of coal.
- Transportation cost was assumed to be 1.5¢ per tonne-km.
- Cost of additional rail car maintenance due to preferential front wheel wear in cover car systems was assumed to be 2% of capital cost.
- Cost of chemical sealants was assumed to be 12¢ per tonne of coal.
- Product loss due to coal dust emissions for chemical sealant controls was assumed to be 0.15% (i.e.: 85% control applied to an uncontrolled emission factor of 1 tonne coal per car per trip).

The estimates in Reference 11 show only a small difference in the amortized cost of a fibreglass lift-off cover system compared to the long term costs of sprayed chemical sealants. However, a bias against chemical binders and in favour of cover systems was introduced when it was assumed that there was a frozen coal carry-back penalty for sprayed cars and none for covered cars. The industry's claim, that covers do not eliminate coal carry-back, has been confirmed by the operator of the automated cover system in the U.S.A., therefore the frozen coal carry-back penalty has been removed for both cover and spray system cost estimates shown in Section C.2.

The industry was also concerned about the product loss factor, (i.e. coal dust loss) included for chemical binders but not for covers, since this factor significantly biased the cost estimates against chemical sprays. Therefore, since losses are unsubstantiated and not a true system cost, the revised estimates include a low estimate with no loss factor plus a high estimate which includes the influence of a product loss factor (85% dust control of a 1% loss).

C.2 Revised Cost Estimates

Many of the parameters which influence the cost of dust control systems and which are used in cost estimating have not been, or cannot be, accurately determined. As noted previously, these uncertainties have lead to controversies with respect to the validity of cost estimates. Therefore, the revised estimates, presented below, incorporate "best" and "worst" assumptions with respect to unsubstantiated variables in order to illustrate the sensitivity of cost estimating. Three types of dust control systems have been considered: sprayed chemical sealants, a fibreglass lift-off cover system, and a steel hinged-cover system.

TABLE C1 FIXED COST FACTORS - ALL DUST CONTROL SYSTEMS

PARAMETER	VALUE
Labour	$20/hour
Transport Cost	$19/tonne
Coal Value	$60/tonne
Spray Chemical Cost	$1/litre
Car Capital Cost	$60 000
Coal Shipped	5 million tonnes per year
No. Coal Mines	2
No. Coal Ports	1
Haul Distance - one way	1 100 km
Travel Time - one way	41 hours
Average Cars per Train	100
Load per Car	91 tonne
Spare Train Sets Required	1%
Interest Rate	15%
Mine Facilities Life	20 years
Port Facilities Life	20 years

In order to compare the influence of individual parameters, a number of factors were fixed at one value for all systems. Table C1 lists the fixed cost factors which were used to estimate the base-case costs for the three control systems. All of the base-case estimates were developed with the values set as indicated.

C.2.1 Chemical Spray Systems. In addition to the fixed factors listed in Table C1, the low, base, and high sensitivity cost estimates (Table C3) for this control system were generated assuming the cost factors listed in Table C2.

The spray system envisaged was similar to those already installed at the coal mine load-outs in western Canada. In addition to the factors listed in Table C2 other parameters were also tested for their influence on the base-case cost. The following (when they were the only parameter varied) were each shown to increase or decrease the amortized costs by a minimal amount:

- To account for chemical sealant spillage at a mine site add a cost factor of 1% per year.

TABLE C2 SPRAY SYSTEM COST FACTORS

	Case	Low	Base	High
-	Labour at mine site:	1 hour	2 hours	4 hours
-	Maintenance at mine site:	4	4% of capital cost	4
-	Weight of fluid per car:	0.225	0.225 tonnes	0.450
-	Litres of spray per car:	10	10	20
-	Uncontrolled dust emissions:	1	1 tonne per car	1
-	Percent dust control:	100%	100%	85%
-	Weight of frozen coal:	0	0 tonnes per car	0
-	Loading time:	4	4 hours	4
-	Unloading time:	4	4 hours	4
-	Round trips per year:	550	550	550
-	Operating days per year:	330	330	330
-	Cost of mine spray apparatus:	100,000	$200,000	$400,000
-	Cost of back-up spray:	$0	$0	$0
-	Cost of leveller:	$0	$0	$0

- To allow for errors in maintenance estimates increase or decrease the maintenance required at a mine site by 1%.
- To operate a more complex load leveller/spray system increase the labour required per train at a mine site from 2 to 4 hours.
- To allow time for improved load levelling, increase the loading time from 4 to 5 hours but do not add extra car charges.
- Increase the working days per year from 330 to 365. (The net effect of this increase was nullified. The accepted practice when cost estimating has been to round-off train set and car requirements to the next higher integer, this round-off produced a buffer which absorbed the effect of an increase in the number of working days).
- To improve spray performance add a $100 000 back-up spray. (Changing no other parameters.)
- To improve spray performance add a $100 000 leveller. (Changing no other parameters.)
- To improve dust control add ONE $100 000 en route water spray device.
- To reduce empty car dusting add One $100 000 port located car wash.

Certain factors, Table C2, appear to have a greater individual influence on sprayed chemical system cost. The quantity, hence cost, of the commercial chemical sealant added per car has the greatest impact on the cost estimates shown in Table C3.

TABLE C3 SPRAY SYSTEM COST ESTIMATES

Equipment and Material costs		Sensitivity Cases Low	Base	High
Capital Costs:	Mines	200,000	400,000	800,000
	Port	-	-	-
	Covers	-	-	-
Annual Costs:				
Capital Recovery:	Mines	31,960	63,920	127,840
	Ports	-	-	-
	Covers	-	-	-
Labour:	Mines	11,000	22,000	44,000
	Port	-	-	-
Maintenance:	Mines	8,000	16,000	32,000
	Port	-	-	-
	Covers	-	-	-
Materials	Spray	500,000	500,000	1,000,000
SUB-TOTAL		550,960	601,920	1,203,840
INDIRECT TRANSPORTATION COSTS				
- Displaced Cargo & Additional Time Costs		235,125	235,125	470,250
- Product Loss		-	-	(495,000)*
- Extra Rail Car Maintenance		-	-	-
TOTAL ANNUAL COST $		786,085	837,045	1,674,090 (2,169,090)*
Costs Per Tonne $		$0.16/tonne	$0.17/tonne	$0.34/tonne ($0.44/tonne)*

* The bracketed cost estimates include a product loss factor. Product loss en route due to fugitive dusting is not a true system cost, it has been included to indicate its importance with respect to other factors.

TABLE C4 FIBREGLASS COVERS COST FACTORS

Case	Low	Base	High
- Labour at the mine site:	4 hours	4 hours	6 hours
- Labour at the port:	4 hours	4 hours	6 hours
- Maintenance at the mine site:	4	4%	4
- Maintenance at the port:	4	4%	4
- Cover maintenance:	4	4%	4
- Cover weight:	0.7 tonnes	1.1 tonnes	1.1 tonnes
- Weight of frozen coal carry-back:	0	0 tonnes/car	0
- Loading time:	4	4 hours	4
- Unloading time:	4	4 hours	4
- Cost per cover:	$4 800	$4 800	$9 000
- Cost per cover installation:	$1 300	$1 300	$1 300
- Cost mine cover handling system:	$1.2 x 10^6	$1 200 000	$2.4 x 10^6
- Cost port cover handling system:	$1.2 x 10^6	$1 200 000	$2.4 x 10^6
- Spare cover requirement:	15	15%	15
- Cover life:	5 years	5 years	5 years

C.2.2 Fibreglass Lift-Off Cover System. The base-case estimates for this control system were made assuming an automatic, fibreglass, lift-off, carry-round, and replace cover design as presented in Reference 11.

In addition to the fixed factors, Table C1, the factors listed in Table C4 were employed to calculate the sensitivity estimates for this control system, Table C5.

Amortization of the capital costs of cover systems over their useful operating lives and the displaced cargo penalties due to cover weight represent the major cost items for this system. Amortization is sensitive to the cover costs and the assumed operating life of each cover system component.

C.2.3 Sectional Steel, Hinged-Cover System. In addition to the fixed factors, Table C1, the assumptions in Table C6 were used for the sensitivity estimates in Table C7.

An estimate of the cost to rebuild rotary dumpers to accomodate car covers was not included. This cost factor was not considered because it was felt that a cover

TABLE C5 FIBREGLASS LIFT-OFF COVER COST ESTIMATES

Equipment and Material costs		Sensitivity Cases Low	Base	High
Capital Costs:	Mines	2,400,000	2,400,000	4,800,000
	Port	1,200,000	1,200,000	2,400,000
	Covers	5,456,000	5,456,000	9,320,000
Annual Costs:				
Capital Recovery:	Mines	383,520	383,520	767,040
	Ports	191,760	191,760	383,520
	Covers	1,087,381	1,627,525	2,780,156
Labour:	Mines	44,000	44,000	66,000
	Port	44,000	44,000	66,000
Maintenance:	Mines	96,000	96,000	192,000
	Port	48,000	48,000	96,000
	Covers	218,240	218,240	372,800
Materials	Spray	-	-	-
SUB-TOTAL		2,112,901	2,653,045	4,723,516
INDIRECT TRANSPORTATION COSTS				
- Displaced Cargo & Additional Time Costs		731,500	1,149,500	1,149,500
- Product Loss		-	-	-
- Extra Rail Car Maintenance		-	-	-
TOTAL ANNUAL COSTS $		2,844,401	3,802,545	5,873,016
Costs Per Tonne $		$0.57/tonne	$0.76/tonne	$1.18/tonne

system should be designed so as to compatible with all existing dumpers rather than redesigning dumpers to accept a pre-designed cover system.

The style of cover envisioned when making the base-case estimate was a long lasting, sectional, steel, hinged-cover system similar to the one in operation in the U.S.A. This system would require only the scroll type of lid-opening mechanism at the mine site and no modifications to the port unloading system (11).

Cover costs, cover weight and extra wheel-maintenance appear to have the greatest impact on overall steel-cover system cost. If the amount of extra wheel-

TABLE C6 STEEL COVERS COST FACTORS

Case	Low	Base	High
- Labour at the mine site and port:	0	0 hours	0
- Maintenance at the mine site:	1	1%	1
- Cover maintenance:	2	2%	2
- Cover weight:	2.27 tonnes	2.27 tonnes	3.4 tonnes
- Weight of frozen coal carry-back:	0	0 tonnes/car	0
- Loading time:	4	4 hours	4
- Unloading time:	4	4 hours	4
- Cost per cover:	$9 000	$9 000	$9 000
- Cost per cover installation:	$1 900	$1 900	$1 900
- Cost of mine cover handling system:	$1 000 000	$1 000 000	$1 000 000
- Cost of mine retrofit (per mine):	$500 000	$500 000	$500 000
- Cover life:	15	15 years	15
- Extra maintenance due to wheelwear:	0%	2%	2%

maintenance could be reduced or eliminated then the cost penalty imposed by this parameter would be less and the system judged economically more attractive. Selecting a cover of the lightest practicable material will also reduce the cover weight cost penalty and reduce overall system cost.

TABLE C7 STEEL HINGED-COVER COST ESTIMATES

Equipment and Material costs		Sensitivity Cases Low	Base	High
Capital Costs:	Mines	1,200,000	1,200,000	1,200,000
	Port	-	-	-
	Covers	9,440,000	9,440,000	9,440,000
Annual Costs:				
Capital Recovery:	Mines	191,760	191,760	191,760
	Ports	-	-	-
	Covers	1,614,240	1,614,240	1,614,240
Labour:	Mines	-	-	-
	Ports	-	-	-
Maintenance:	Mines	12,000	12,000	12,000
	Port	-	-	-
	Covers	188,800	188,800	188,800
Materials	Spray	-	-	-
SUB-TOTAL		2,006,800	2,006,800	2,006,800
INDIRECT TRANSPORTATION COSTS				
- Displaced Cargo & Additional Time Costs		2,372,150	2,372,150	3,553,000
- Product Loss		-	-	-
- Extra Rail Car Maintenance		-	960,000	960,000
TOTAL ANNUAL COST $		4,378,950	5,338,950	6,519,800
Costs Per Tonne $		$0.88/tonne	$1.07/tonne	$1.31/tonne